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Stöðuskýrsla vegna fyrsta árs RÁV verkefnisins

REYKJAVÍK
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1 INNGANGUR

Í júlí 2006 gerðu Háskóli Íslands (HÍ), Landsnet (LN), Landsvirkjun (LV). Orkustofnun (OS), Orkuveita Reykjavíkur (OR), Reiknistofa í veðurfræði (RV) og Veðurstofa Íslands (VÍ) með sér samning um styrkveitingu til rannsóknaverkefnisins "Reikningar á veðri - RÁV". Í ársbyrjun 2007 fékkst að auki öndvegisstyrkur frá Rannsóknasjóði Íslands til þessa verkefnis, hefur það því hlotið nýtt nafn; RÁVÖndin.

Stýrihóp verkefnisins skipa Haraldur Ólafsson (HÍ) – formaður, Ólafur Rögnvaldsson (RV) – dagleg umsjón, Halldór Björnsson (VÍ) og Óli Grétar Blöndal Sveinsson (LV).

Í stöðuskýrslu þessari verður farið yfir verkþætti sem unnir hafa verið á fyrsta ári verkefnisins og mat lagt á framgang verkefnisins í heild sinni. Ennfremur eru gerð skil á ritrýndum greinum, ráðstefnuritgerðum og skýrslum sem unnar hafa verið í tengslum við verkefnið.

Í desember 2006 kom út áfangaskýrsla fyrir verkefnið[1] og í febrúar 2007 var haldinn kynningarfundur fyrir aðstandendur RÁVAndarinnar þar sem niðurstöðum og framgangi verkefnisins voru gerð ítarleg skil.

Frumniðurstöður þróunarvinnu á hviðu- og jaðarlagslíkani voru kynntar á ICAM ráðstefnunni í Chambéry í Frakklandi og á WRF ráðstefnunni í Boulder í Bandaríkjunum í júní 2007.

Að verkinu hafa unnið Einar M. Einarsson (RV), Halldór Björnsson (VÍ), Haraldur Ólafsson (HÍ), Hálfdán Ágústsson (RV), Hrafnkell Pálsson (RV), Ólafur Rögnvaldsson (RV), Sveinbjörn J. Tryggvason (RV), Sveinbjörn Brynjólfsson (HÍ/VÍ), Þórður Arason (VÍ) og Örnólfur E. Rögnvaldsson (RV).

2 MARKMIÐ

Markmið verkefnisins er að spá fyrir og kortleggja hita, úrkomu og vind í þéttu reiknineti við núverandi veðurfar. Ennfremur að þróa frekar tæki og hugbúnað til að kanna fyrrgreinda veðurþætti í núverandi og framtíðarveðurfari.

3 VÖRÐUR, TÍMA– OG KOSTNAÐARÁÆTLUN

Helstu vörður verkefnisins eru:

1) Verkþættir er lúta sérstaklega að spákerfinu – þróun hugbúnaðar til að flytja reiknigögn úr spákerfinu inn í gagnasjá VÍ; vistun punktgagna; endurskoðun landgerðar; endurskoðun daglegra keyrslna.

2) Bestun og sannreyning á úrkomustikunum. **Þessi vinna fer fram á 1. og 2. ári**.

3) Bestun, sannreyning og þróun jaðarlagslíkans. **Þessi vinna fer fram á 1. og 2. ári verkefnisins**.

4) Þróun, bestun og sannreyning á hviðulíkani. **Unnið á 1. til 3. ári**.

5) Háupplausnarreikningar á veðri á Íslandi. **Unnið á 3. ári**.

6) Þróun og uppsetning gagnagrunns. **Unnið á 1. og 2. ári, notast verður við fyrirliggjandi reiknigögn við hönnun grunnsins**.

[1] Skýrslan er aðgengileg á vefnum: www.betravedur.is/or/RAV/stoduskyrslaRAV–nov06.pdf

7) Ritun vísindagreina um niðurstöður verkefnisins. **Unnið á 2. og 3. ári**.

8) Niðurstöður verða kynntar á Íslandi og á ráðstefnum erlendis. **Öll ár verkefnisins**.

Verkþættir 2–4, 7 og 8 verða unnir í nánu samstarfi við erlendar rannsóknastofnanir og/eða háskóla. Tafla 1 sýnir áætlaða kostnaðardreifingu vegna verkþátta sem unnir voru á fyrsta ári RÁVAndar verkefnisins.

Tafla 1. *Kostnaðaráætlun vegna fyrsta verkárs.*

Verkþáttur	Vinna	Tæki/hugbúnaður
Gagnaframsetning	1.500 þkr	
Vistun punktgagna	1.000 þkr	500 þkr (vél– og hugbúnaður)
Endurbætur landgerðar	2.000 þkr	
Endurskoðun daglegra keyrslna	1.500 þkr	
Þróun gagnagrunns	1.000 þkr	
Þróun hviðulíkans	2.000 þkr	
Þróun úrkomustikana	2.000 þkr	500 þkr (úrkomumælar)
Þróun jaðarlagslíkans	1.800 þkr	
Afskriftir og aðstaða		2.200 þkr
Heild:	**12.800 þkr**	**3.200 þkr**

4 VERKÞÆTTIR

4.1 Gagnaframsetning

Daglegar veðurspár eru birtar á vefnum www.belgingur.is og eru þær uppfærðar átta sinnum á sólarhring. Helgast það af því að spárnar eru reiknaðar út frá lofthjúpsgreiningum og spám frá bæði Bandarísku (NOAA – GFS) og Evrópsku (ECMWF) veðurstofunum. Báðar þessar veðurstofur uppfæra lofthjúpsgreiningar sínar og spár fjórum sinnum á sólarhring. Þessum lið verkefnisins er lokið og verður öll frekari þróun gagnaframsetningar fjármögnuð utan RÁVAndar verkefnisins.

4.2 Endurbætur landgerðar

Sjá umfjöllun síðar í greinargerðinni.

4.3 Endurskoðun daglegra keyrslna

Sjá umfjöllun síðar í greinargerðinni.

4.4 Þróun gagnagrunns

Vistun punktgagna er hluti af almennri uppbyggingu gagnabanka sem hýsa skal gögn er koma munu út úr líkankeyrslum í hárri upplausn (áætlað á 3. ári RÁVAndar verkefnisins). Til viðbótar við vistun punktgagna hefur verið sett upp svokallað OpENDAP kerfi (www.opendap.org) og unnið er að uppsetningu hugbúnaðar er leyfir vefaðgang að DB2 gagnagrunni Reiknistofu í veðurfræði (RV). Þessi vinna hefur reynst töluvert umfangsmeiri en gert var ráð fyrir í fyrstu áætlunum. Óhætt er að áætla að töluverð vinna sé eftir hvað uppsetningu og þróun grunnsins varðar til að tryggt sé að hann verði sem best úr garði gerður. Leitað verður eftir utanaðkomandi sérfræðiþekkingu þar sem innanbúðarfólki þrýtur visku í þessum efnum.

Loks verður öryggisafrit af gagnagrunni VÍ, eða a.m.k. hluta hans, vistað á vélum RV og ennfremur gert aðgengilegt í gegnum fyrrnefnt vefaðgengi. Notkunarleiðbeiningar með grunninum verða skrifaðar þegar vefaðgengi að honum kemst í gagnið.

4.5 Þróun hviðulíkans

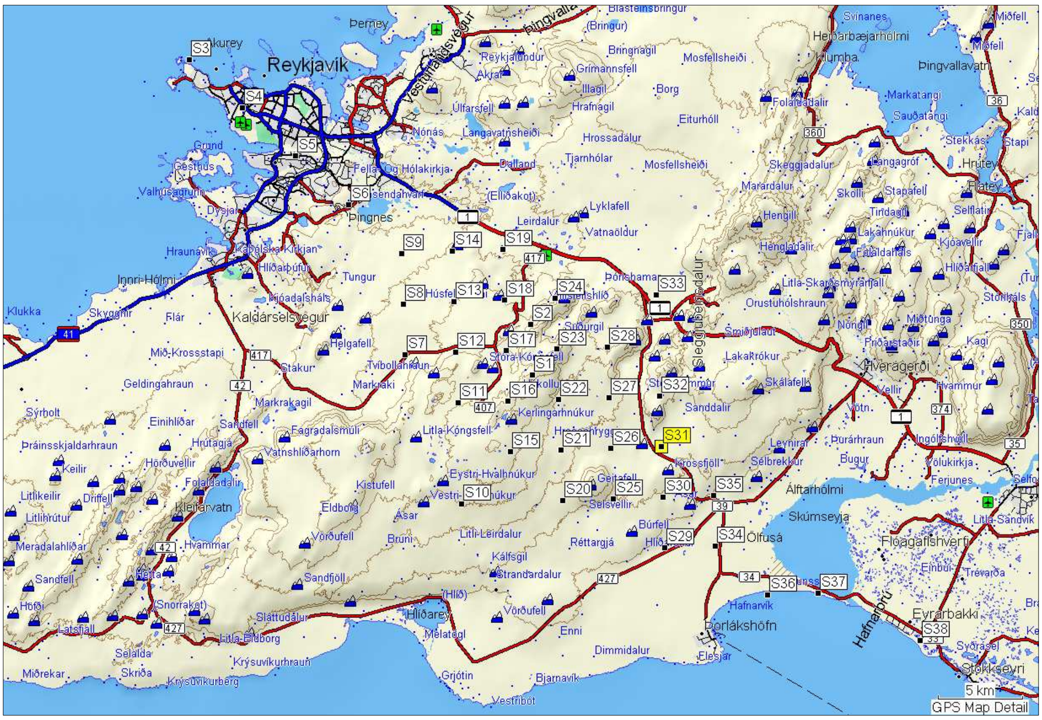
Undanfarin misseri hefur verið unnið að þróun og prófunum á aðferð til að spá fyrir um vindhviður m.v. niðurstöður reikninga með lofthjúpslíkani, ýmist MM5 eða AR–WRF. Þessi verkþáttur er á áætlun og vísað er í ritrýnda grein (Ólafsson and Hálfdán Ágústsson 2007) sem birtist nýverið í alþjóðlega fagritinu *Meteorologische Zeitschrift* og fylgiskjal með ráðstefnuritgerð (á ensku) vegna ICAM–ráðstefnunnar 2007. Þar er aðferðin prófuð við mismunandi aðstæður og varpað er ljósi á þætti í hviðulíkaninu sem þarfnast frekari athugana við. Ný grein um hviðuspárnar er í vinnslu og má ætla að ritun hennar ljúki á haustmánuðum 2007. Fyrstu niðurstöður þessara rannsókna eru það lofandi að hviðulíkanið hefur verið sett í prófun í daglegum keyrslum og spárnar birtar á sérstakri tilraunavefsíðu: www.betravedur.is. Frekari þróun á hviðulíkaninu helst í hendur við þróun jaðarlagslíkansins og aðferða innan þess til stikunar á kviku.

4.6 Þróun úrkomustikana

Unnið hefur verið að prófunum og næmnireikningum á úrkomudreifingu með veðurlíkaninu MM5. Niðustöður birtust nýverið í ritrýndri grein (Rögnvaldsson et al. 2007) í *Meteorologische Zeitschrift*. Helstu niðurstöður voru að úrkomudreifing reiknuð með veðurlíkaninu MM5 er mjög næm fyrir stærð svonefndra þéttikjarna (e. Cloud Condensation Nuclei – CCN), en þeir eru ráðandi þáttur í því hvenær líkanið myndar dropa, og þar með úrkomu. Ennfremur var úrkomudreifing mjög háð láréttri upplausn líkansins sem og upphafs– og jaðarskilyrðum. Nýverið hefur verið sett upp mun þéttara net úrkomumæla á Reykjanesinu (sjá mynd 1) og eru vonir bundnar við að mæliniðurstöður muni nýtast við áframhaldandi bestun úrkomustikana í nýju veðurlíkani, AR–WRF, sjá frekari umfjöllun í *Endurskoðun daglegra keyrslna* hér á eftir.

4.7 Þróun jaðarlagslíkans

Í marsmánuði síðastliðnum unnu tveir starfsmenn Reiknistofu í veðurfræði við rannsóknir hjá Bandarísku haf- og lofthjúpsfræðistofnunni (NOAA/ESRL). Meðal verkefna var m.a. að setja upp svokallað Bao jaðarlagslíkan inn í nýjustu útgáfur af bæði MM5 og AR–WRF veðurlíkönunum. Sú vinna er langt komin og standa prófanir yfir. Reiknuð hafa verið nokkur sértilvik af þekktum óveðrum, bæði á sunnanverðu Snæfellsnesi sem og undir Öræfajökli. Sjá frekar í umfjöllun um *Endurskoðun daglegra keyrslna* hér á eftir. Áfram verður unnið að þróun jaðarlagslíkansins, hviðulíkaninu verður þar bætt inn í og lengri tímabil reiknuð og næmni jaðarlagslíkansins könnuð frekar.



LIC_831, R. Sigmundsson ID831

Mynd 1. *Mælanet vegna SKÚR (Staðbundin kortlagning úrkomu á Reykjanesi) verkefnisns. Grunnmynd fengin frá R. Sigmundsson ehf. S1 til S37 tákna staðsetningu úrkomumæla.*

5 VERKÞÆTTIR ERU SNÚA SÉRSTAKLEGA AÐ VEÐURSPÁKERFI

RV og VÍ sömdu sérstaklega um greiðslutilhögun og var lögð áhersla á þá verkþætti innan RÁV er lutu sérstaklega að veðurspákerfi því er þróað hefur verið á síðastliðnum árum í samvinnu RV og VÍ (einnig nefnt HRAS verkefnið). Þessir verkþættir eru eftirfarandi (áætlaður fjöldi mannmánaða innan sviga):

1) Þróun hugbúnaðar til að flytja reiknigögn úr spákerfinu inn í gagnasjá VÍ (2mm).

2) Vistun punktgagna úr spákerfinu í gagnagrunn (1mm).

3) Endurbætt landgerð (6mm).

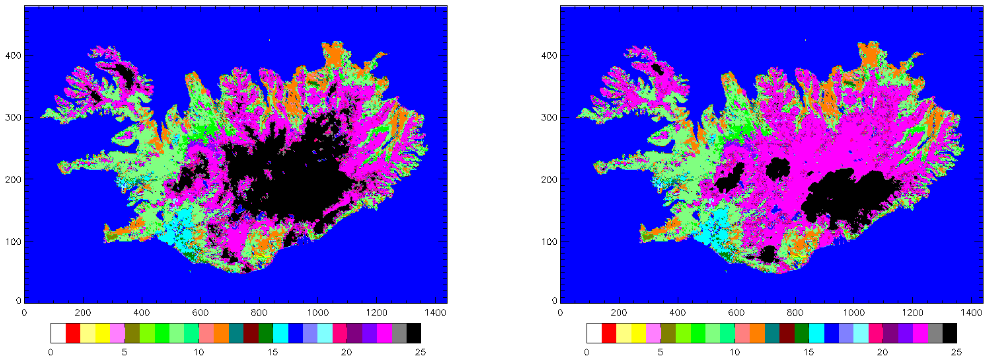
4) Endurskoðun daglegra keyrslna (3mm).

Skemmst er frá því að segja að verkliðum 1 og 2 er lokið og er vísað til áfangaskýrslu fyrir RÁV verkefnið[2] frá því í nóvember 2006 varðandi lýsingu á þeim. Niðurstöður voru ennfremur kynntar frekar fyrir samstarfsaðilum á fundi í febrúar 2007. Nánari verklýsing liða 3 og 4 er sem hér segir.

5.1 Endurbætt landgerð

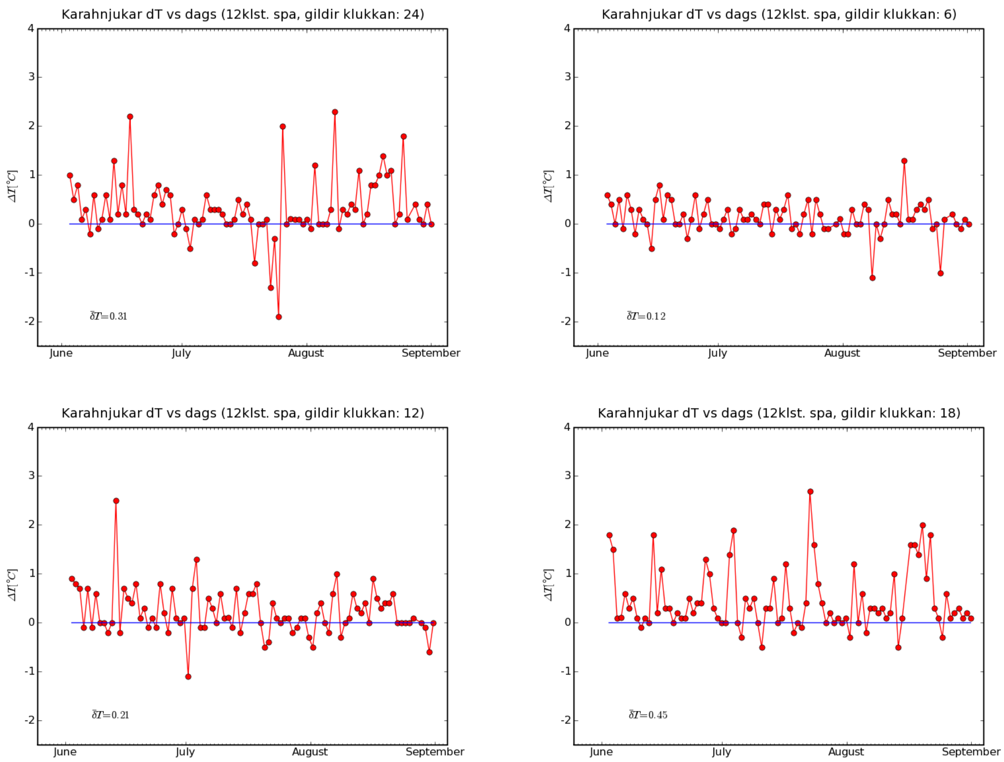
Meðal niðurstaða úr HRAS verkefninu var að lofthiti væri að líkindum kerfisbundið rangur sumsstaðar á landinu í hægum vindi, einkum að sumarlagi. Ástæða er til að ætla að það leiðréttist við endurskoðun á landgerð spálíkansins. Endurbætur hafa verið gerðar á landgerðinni.

[2]Skýrslan er aðgengileg á vefnum: www.betravedur.is/or/RAV/stoduskyrslaRAV–nov06.pdf



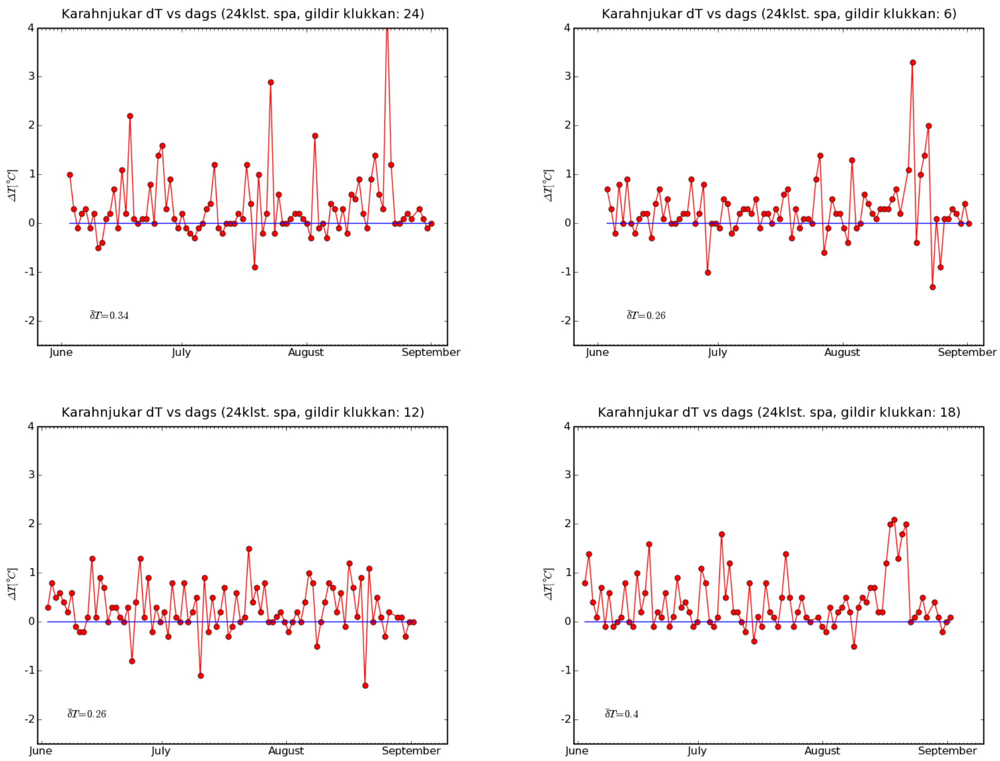
Mynd 2. *Upprunaleg (vinstri) og breytt (hægri) landgerð, svartur litur táknar jökla/snævi.*

Mestu munar nú um að Vatnajökull og jöklar á hálendi landsins eru mun betur skilgreindir en áður var (sjá mynd 2). Eldri skilgreiningar voru byggðar á gerfihnattamælingum frá apríl 1992 til mars 1993.



Mynd 3. *Mismunur á reiknuðum hita á Kárahnjúkum fyrir 12 klst. spár (breytt mínus óbreytt landgerð) frá júní og út ágúst 2006.Gildistími spánna er miðnætti (efst til vinstri), 6 að morgni (efst til hægri), hádegi (neðst til vinstri) og 18 síðdegis (neðst til hægri).*

Lokið hefur verið við endurkeyrslur á 9 km spám fyrir sumarmánuðina (júní út ágúst) með sömu upphafs– og jaðarskilyrðum, en leiðréttri landgerð. Með þessu móti fæst beinn samanburður á 12, 24 og 36 klukkustunda spám, fjórum sinnum á sólarhring, þar sem eini munurinn felst í landgerð. Myndir 3 til 5 sýna hitamun úr þessum tveimur keyrslum á Kárahnjúkum fyrir 12, 24 og 36 klukkustunda spár. Á hverri mynd er hitamunur sýndur á miðnætti, klukkan 6 að morgni, hádegi og klukkan 18 síðdegis. Á mynd 3 má sjá að reiknaður hiti er að jafnaði 0.12 til 0.45 °C hærri í líkaninu með leiðréttri landgerð. Að jafnaði er munurinn minnstur að morgni (0.12 °C) en mestur klukkan 18 síðdegis (0.45 °C). Mynd 4 sýnir að

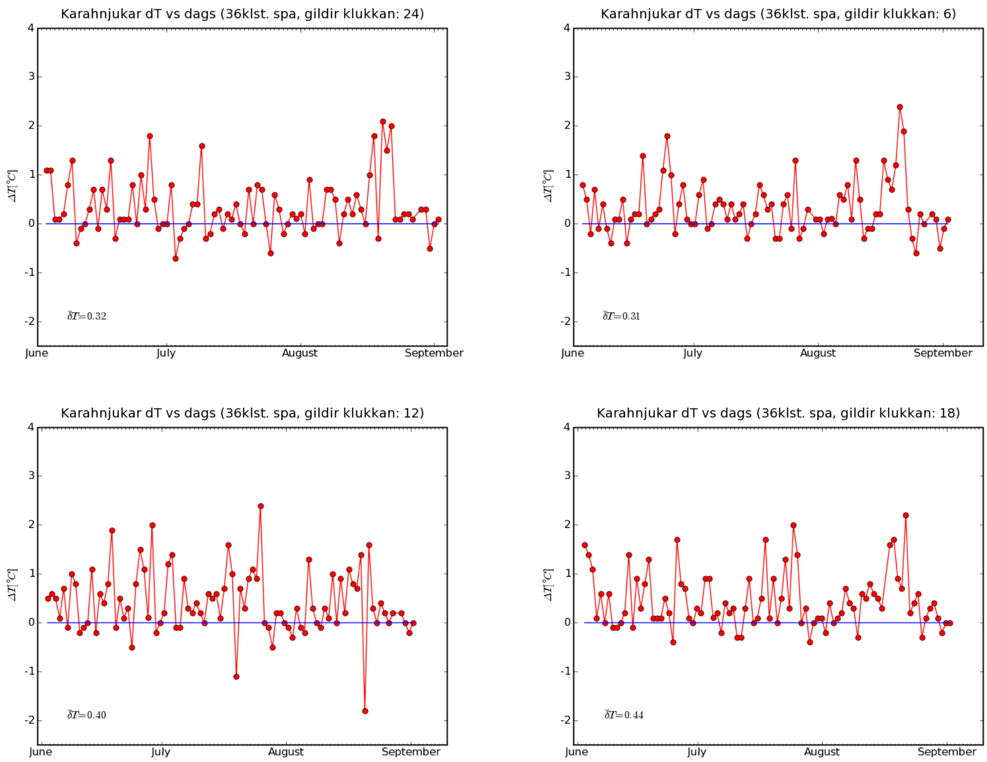


Mynd 4. *Mismunur á reiknuðum hita á Kárahnjúkum fyrir 24 klst. spár (breytt mínus óbreytt landgerð) frá júní og út ágúst 2006.Gildistími spánna er miðnætti (efst til vinstri), 6 að morgni (efst til hægri), hádegi (neðst til vinstri) og 18 síðdegis (neðst til hægri).*

reiknaður hiti er að jafnaði 0.26 til 0.4 °C hærri í líkaninu með uppfærðri landgerð. Líkt og fyrir 12 klukkustunda spárnar þá er hitamunurinn minnstur fyrri hluta dags (0.26 °C klukkan 6 að morgni og klukkan 12 á hádegi) en mestur klukkan 18 síðdegis (0.4 °C). Á mynd 5 má loks sjá að reiknaður hiti er að jafnaði 0.31 til 0.44 °C hærri í líkaninu með uppfærðri landgerð. Að jafnaði er munurinn minnstur að nóttu og snemma morguns, 0.32 °C á miðnætti og 0.31 °C klukkan 6 að morgni. Sem fyrr er hitamunurinn mestur klukkan 18 síðdegis (0.44 °C).

Sé reiknaður hiti borinn saman við mældan hita á Kárahnjúkum (mynd 6) sést að staðalfrávik og RMS villur minnka mikið sé reiknað með nýju landgerðinni. Ennfremur hækkar Spearman fylgnistuðullinn mikið eða úr 0.62 til 0.65 í 0.85 til 0.90. Samantekt á mynd 6 er að finna í töflu 2.

Þessi miklu hitafrávik í spánum er eingöngu að finna á svæðum í grennd við jökla landsins, þ.e. þeim svæðum þar sem mestar breytingar urðu á landgerðinni. Til marks um þetta má nefna að hitamunur á 12, 24 og 36 klukkustunda spám fyrir Reykjavík er á bilinu 0.0 til 0.04 °C.



Mynd 5. *Mismunur á reiknuðum hita á Kárahnjúkum fyrir 36 klst. spár (breytt mínus óbreytt landgerð) frá júní og út ágúst 2006.Gildistími spánna er miðnætti (efst til vinstri), 6 að morgni (efst til hægri), hádegi (neðst til vinstri) og 18 síðdegis (neðst til hægri).*

5.2 Endurskoðun daglegra keyrslna

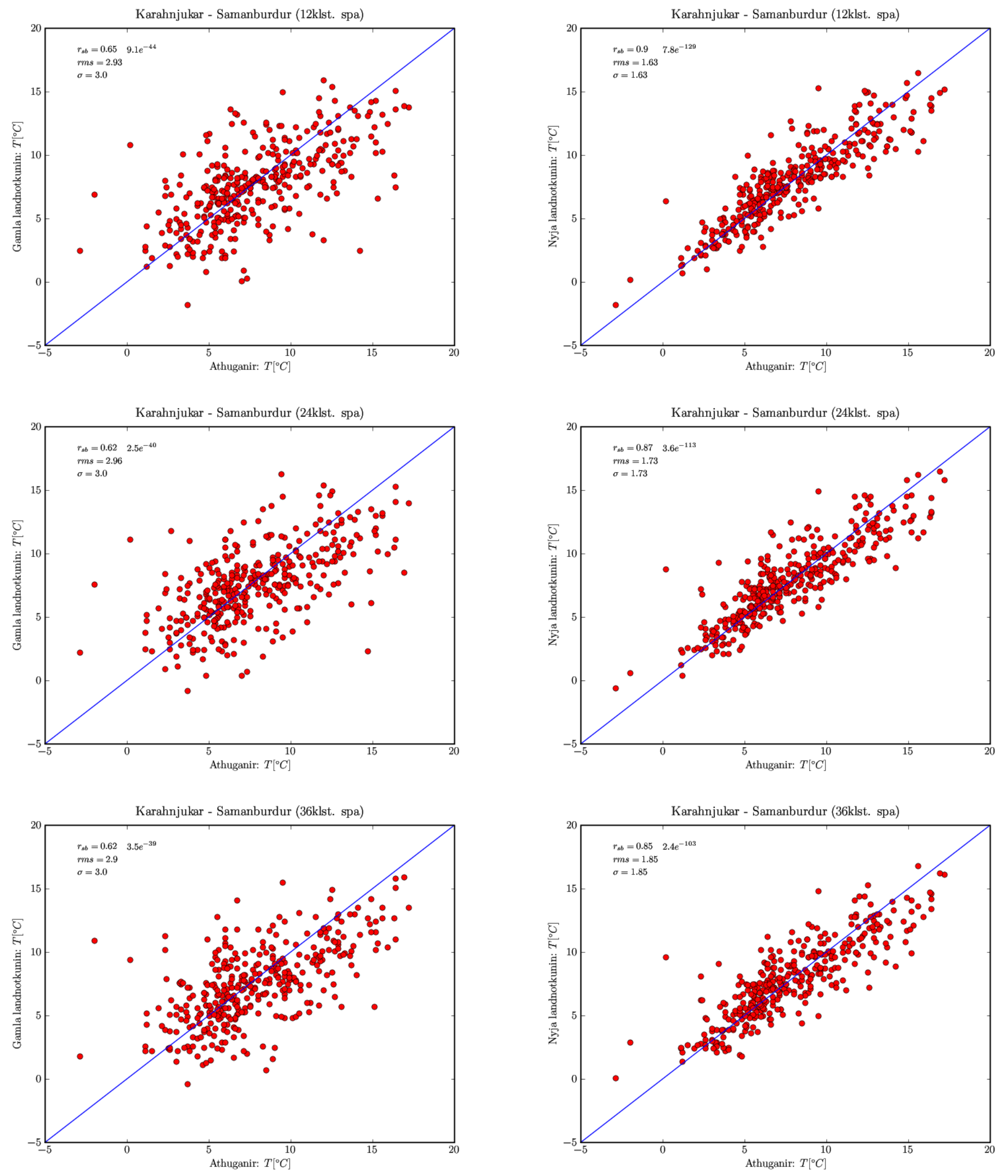
Síðastliðin átta ár hefur verið í þróun í Bandaríkjunum nýtt veðurlíkan í samstarfi NCAR, NOAA, NCEP, FSL, AFWA og FAA auk ýmissa háskóla. Nefnist líkanið í daglegu tali WRF (e. Weather, Research and Forecasting model). WRF líkanið (www.wrf–model.org) er hugsað sem arftaki MM5 veðurlíkansins og hefur allri þróun á síðarnefnda líkaninu nú verið hætt en þeim mun meiri áhersla verið lögð á áframhaldandi þróun á WRF.

Tveir starfsmenn RV, þeir Hálfdán Ágústsson og Ólafur Rögnvaldsson, unnu að rannsóknum hjá Bandarísku haf– og lofthjúpsfræðistofnunni (NOAA/ESRL) í Boulder í mars síðastliðnum. Unnið var að koma nýju jaðarlagslíkani (svokölluðu Bao jaðarlagslíkani) inn í MM5 og AR–WRF (e. Advanced Research WRF) veðurlíkönin sem og að koma hvirflalíkani (e. LES – Large Eddy Simulation model) inn í AR–WRF veðurlíkanið. Valin veður voru reiknuð með báðum líkönum og niðurstöður bornar saman við mælingar. Frumniðurstöður þessara rannsókna voru kynntar á ráðstefnum í Frakklandi og Bandaríkjunum í júní 2007 en greinargerðir þar að lútandi (á ensku) eru fylgiskjöl með skýrslu þessari.

Ein meginniðurstaða þessarar vinnu er að hið nýja AR–WRF veðurlíkan ræður mun betur við að líkja eftir vindstormum hlémegin fjalla. Fyrstu niðurstöður benda ennfremur til að reiknuð úrkomudreifing í AR–WRF líkaninu sé líkari mældri en í MM5 líkaninu. Ennfremur virðist sem bandaríska lofthjúpsgreiningin (NOAA - GFS), og tilsvarandi veðurspá, gefi betri

Tafla 2. *Spearman fylgnistuðlar, RMS villur og staðalfrávik reiknaðs hita fyrir upphaflegu og endurbættu landgerðina við Kárahnjúka.*

Stuðull	**12 klst. spá**		**24 klst. spá**		**36 klst. spá**	
	Upphafleg	Endurbætt	Upphafleg	Endurbætt	Upphafleg	Endurbætt
Spearman	0.65	0.90	0.62	0.87	0.62	0.85
RMS villa	2.93	1.63	2.96	1.73	2.9	1.85
Staðalfrávik	3.0	1.63	3.0	1.73	3.0	1.85



Mynd 6. *Mældur og reiknaður (upphafleg landgerð til vinstri, endurbætt til hægri) hiti á Kárahnjúkum frá júní og út ágúst 2006. Spátími er 12 klst. (efst), 24 klst. (mið) og 36 klst. (neðst). Athuganir eru á láréttum ás og reiknaður hiti á lóðréttum ás.*

niðurstöður en sú evrópska (ECMWF), a.m.k. við núverandi lóðrétta upplausn þeirrar síðarnefndu og fyrir þau einstöku veður sem reiknuð voru. Kanna þarf betur hvernig evrópska lofthjúpsgreiningin, í fullri lóðréttri upplausn, kemur út í samanburði við þá bandarísku. Til þessa hefur verið settur upp hugbúnaður frá Max-Planck stofnuninni í Þýskalandi sem gerir kleift að brúa evrópsku lofthjúpsgreininguna af líkanflötum yfir á þrýstifleti. Er það nauðsynlegt til að hægt sé að nota greininguna (og viðkomandi spá) sem innlag inn í MM5 og AR–WRF veðurlíkönin. Fyrstu kannanir benda til að þetta verklag muni skila tilætluðum árangri, þ.e. ekki taki það langan tíma að forvinna greininguna að óásættanlegar tafir verði á gerð veðurspánna. Ennfremur verður hægt að forvinna eldri lofthjúpsgreiningar Evrópsku veðurstofunnar með sambærilegum hætti. Eitt atriði veldur því þó að ekki hefur verið hægt að nota þennan hugbúnað enn sem komið er. Það kom í ljós að á líkanflötum evrópsku greiningarinnar er mættishæð (e. geopotential height) eingöngu vistuð á neðsta líkanfleti. Veldur þetta því að ekki er hægt að brúa téða breytu yfir á þrýstifleti. Þar sem mættishæð er nauðsynleg innlagsbreyta fyrir bæði AR–WRF og MM5 er nauðsynlegt að leysa þetta vandamál áður en hægt verður að nota greininguna frá Evrópsku veðurstofunni (ECMWF) með fullri lóðréttri upplausn. Sérfræðingar ECMWF hafa verið látnir vita af vandamálinu og er það mál „í vinnslu“.

Annað tæknilegt útfærsluatriði sem kom í ljós að betur mætti fara er uppröðun lóðflata í MM5 veðurlíkaninu. Hermdur vindur hlémegin fjalla kom betur út með tilliti til mælinga, ef lóðflötum í neðstu 1500 metrum lofthjúpsins var fjölgað frá því sem nú er. Ennfremur varð mikil bót á reiknuðu hitastigi nærri yfirborði jarðar við sömu breytingu. Skýrist það af því að neðsti lóðflötur í núverandi uppsetningu er of neðarlega til að stikun flæðis við yfirborð (e. surface flux) sé bestuð.

Rannsóknir erlendis frá (www.rap.ucar.edu/asr2003/land–surface–modeling.html) og (Mitchell 2006) benda til að við notkun yfirborðslíkans verði hermun úrkomu og varmaflæðis við yfirborð betri og köld hitahneigð (e. cold temperature bias) verði minni, einkum ef yfirborð er gróðurvana. MM5 líkanið hefur verið keyrt yfir 10 mánaða tímabil (janúar til og með október 2006) með yfirborðslíkani fyrir óbreytta landgerð. Til að kanna áhrif bættrar landgerðar enn frekar stendur til að keyra líkanið yfir sama tímabil og með sömu uppsetningu, fyrir utan að nota lagfærða landgerð. Með þessu móti fást mikilvægar upplýsingar, ekki bara um áhrif bættrar landgerðar, heldur líka um áhrif þess að keyra veðurlíkan með sérstöku yfirborðslíkani og samspil þess og landgerðar.

Náðst hefur samkomulag milli Veðurstofu Íslands og Evrópsku veðurstofunnar (ECMWF) um að hætta að senda innlagsgögn á svokölluðu „ramma sniði“. Í þessu felst að hægt verður að nota núverandi veðurlíkön (MM5 og AR–WRF) með yfirborðslíkani og óbreyttum forvinnslu hugbúnaði. Í „römmunum“ fólst að jaðargögn (í þessu tilviki veðurspár) voru eingöngu skilgreind á takmörkuðu svæði, ramma, sem lá í kringum Ísland. Til að geta notað yfirborðslíkan í veðurlíkönunum hefðu þessar upplýsingar þurft að vera aðgengilegur fyrir allt svæðið. Með nýjum gagnastraumi frá ECMWF verður þetta mögulegt og standa vonir til að hægt verði hefja þessar endurbættu keyrslur á allra næstu mánuðum.

Einn kostur sem AR–WRF líkanið hefur fram yfir MM5 er að hægt er að skilgreina „svamp“ í efstu lögum líkansins. Með þessu móti er hægt að dempa lóðrétt endurvarp þyngdarbylgna, en líkur eru á að slíkt endurvarp valdi á stundum kindugu úrkomumynstri í veðurspám reiknuðum með MM5 líkaninu. Sökum þessa, og fyrrnefndra kosta AR–WRF líkansins umfram MM5, hefur verið hætt við að kanna áhrif breyttra jaðarskilyrða við efri mörk MM5 líkansins á úrkomudreifingu. Þess í stað hefur verið hafist handa við að setja upp AR–WRF veðurlíkanið til daglegra veðurspáa.

Loks gefa rannsóknir á áhrifum aukinnar láréttrar upplausnar á gæði lofthjúpsreikninga til kynna að bæta megi spárnar enn frekar með aukinni upplausn. Niðurstöður nýbirtra greina

(Ólafsson and Hálfdán Ágústsson 2007; Ágústsson and Haraldur Ólafsson 2007) í tímaritinu *Meteorologische Zeitschrift* sýna að bæta má spárnar töluvert í óveðrum í flóknu landslagi, t.d. með að auka upplausn úr 3km í 1km. Með nýjustu lofthjúpslíkönum, s.s. AR–WRF má auka upplausnina enn frekar. Ennfremur hafa sterkar líkur verið leiddar að því að bæta megi flugveðurspár nokkuð með aukinni láréttri upplausn (Ólafsson and Ágústsson 2006).

Að endingu er rétt að taka fram að uppsetning AR–WRF líkansins til daglegra veðurspáa getur ekki talist falla undir RÁVAndar verkefnið og verður sú vinna fjármögnuð eftir öðrum leiðum.

5.2.1 Samantekt og tillögur

Þrátt fyrir að ekki sé lokið við að kanna til fullnustu áhrif breyttrar landgerðar og yfirborðslíkans né heldur áhrif aukinnar lóðréttrar upplausnar innlagsgagna þá er lagt til að uppsetningu daglegra reikninga verði breytt sem hér segir.

1) Endurbætt landgerð hefur verið tekin í gagnið fyrir spár byggðar á GFS greiningu. Stefnt er að því að allar spár verði reiknaðar með uppfærðri landgerð frá og með mánaðarmótunum júní/júlí 2007. Skiptir þetta miklu máli þar eð rétt lögun og sköpulag jökla hefur mest að segja á sumrin þegar hálendi landsins er að mestu snjólaust.

2) Farið verði að nota yfirborðslíkan (e. LSM) í veðurspárlíkaninu. Þetta krefst nýs gagnastraums frá Evrópsku veðurstofunni (ECMWF) þar sem „ramma“ sniði verður kastað fyrir róða. Formleg beiðni þar að lútandi þarf að koma frá Veðurstofu Íslands.

3) Uppröðun lóðréttra reikniflata verði breytt, fjölga þarf flötum í neðstu 1500 metrunum. Má ætla að vindhraði í óveðrum hlémegin fjalla verði hermdur betur sem og hiti við yfirborð.

4) Áfram verði unnið að aðlaga gögn á líkanflötum ECMWF yfir á þrýstifleti. Ástæða er til að ætla að mikilvægar upplýsingar um ástand lofthjúpsins glatist við núverandi upplausn lóðflata.

5) Unnið verði áfram að uppsetningu og aðlögun AR–WRF veðurlíkansins með það fyrir augum að það leysi núverandi (MM5) líkan af hólmi á næsta verkári.

6) Með auknu reikniafli verði stefnt að því að auka enn frekar lárétta upplausn reikninetsins, a.m.k. fyrir ákveðin landsvæði.

Verkliðnum *Endurskoðun daglegra keyrslna* telst því lokið hvað snertir RÁVAndar verkefnið.

6 VERKÁÆTLUN ANNARS ÁRS RÁVANDARINNAR

Eins og getið var í upphafi þá hlaut RÁV verkefnið öndvegisstyrk frá Rannsóknasjóði Íslands í febrúar síðastliðnum. Í ljósi þessa þá mun verkefnið verða útvíkkað nokkuð, einkum er lítur að þróun á aðferðum til að meta áhættu á ýmsum veðurþáttum í tíma og rúmi. Samstarfsaðilum fjölgar ennfremur en Hending ehf og verkfræðistofan Vatnaskil munu nú leggja hönd á plóg auk starfsmanna HÍ, RV og VÍ. Tafla 3 sýnir verkáætlun fyrir annað ár RÁVAndarinnnar.

Tafla 3. *Verk– og tímaáætlun fyrir annað ár RÁVAndar verkefnisins.*

Verkþáttur	**Fjöldi mannmánaða**	**Starfsstaður**
Verkstýring	4	HÍ(1), RV(2), VÍ(1)
Hermireikningar	1	RV(1)
Gagnavinnsla (mæld gögn) (Gufuskálar+Falcon+FloHof)	8	RV(6), HÍ(1), VÍ(1)
Þróun gagnagrunns og gagnaaðgengis	8	RV(8)
Þróun, bestun og sannreyning jaðarlagslíkans	13	HÍ($\frac{1}{2}$), RV($12\frac{1}{2}$)
Þróun á aðferðum til áhættumats	11	HÍ($1\frac{1}{2}$), Hending(2), RV($7\frac{1}{2}$)
Umsjón hug- og vélbúnaðar	1	RV(1)
Umsjón doktorsnema	1	HÍ(1)
Kynning á (frum)niðurstöðum	3	RV(3)
Ritun niðurstaðna í ritrýnd fagtímarit	5	HÍ(1), RV(4)
Áætlaður heildarfjöldi mann–mánaða fyrir 2. verkár	**57**	**Hending(2), HÍ(6), RV(46), Vatnaskil(1), VÍ(2)**

7 SAMANTEKT

Af framangreindu má ljóst vera að vinna við RÁVAndar verkefnið gengur samkvæmt áætlun og ef eitthvað er þá eru kjarnaþættir verkefnisins á undan áætlun, verkefnið er ennfremur innan upphaflegs fjárhagsramma fyrsta verkárs. Er það eingöngu uppbygging gagnagrunnsins sem tekið hefur lengri tíma en áætlað var í upphafi og gera má ráð fyrir að kostnaður vegna hans verði nokkuð hærri en áætlað var í fyrstu. Loks er vert að benda á nokkurn fjölda ritrýndra greina sem þegar hafa verið gefnar út og byggja að miklu leyti á þessu verkefni þrátt fyrir að það sé enn tiltölulega skammt á veg komið.

Reykjavík, 28. júní 2007.

F.h. stýrihóps RÁVAndar verkefnisins:
Haraldur Ólafsson – formaður stýrihóps   Ólafur Rögnvaldsson – dagleg umsjón

8 HEIMILDIR

Mitchell, K. 2006. The new Noah LSM in the NCEP GFS: (implemented 31 May 2005). THORPEX workshop. Available on the web: http://mc.ncep.noaa.gov/gmb/ens/ THORPEX/PI–workshop/Mitchell_THORPEX–Workshop_GFS–Noah_18Jan06.ppt.

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FYLGISKJÖL

Greinargerð um flugatvik yfir S–Grænlandi í desember 2005: *Observational and numerical evidence of strong gravity wave breaking over Greenland.* Rit Reiknistofu í veðurfræði, ISBN 9979–9709–3–6, Reykjavík, júní 2006.
ICAM ráðstefnuritgerð varðandi hviðulíkanið: *Forecasting wind gusts in complex terrain*, Chambéry, Frakkland, júní 2007.
Veggspjald kynnt á “8th WRF workshop”: *Downslope windstorms in Iceland – WRF/MM5 model comparison – II*, Boulder, BNA, júní 2007.
WRF ráðstefnuritgerð um samanburð á MM5 og AR–WRF líkönunum: *Downslope windstorm in Iceland – WRF/MM5 model comparison – I*, Boulder, BNA, júní 2007.

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Haraldur Ólafsson
Hálfdán Ágústsson

Observational and numerical evidence of strong gravity wave breaking over Greenland

Reykjavík
2006

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ABSTRACT

Severe turbulence was observed over S-Greenland on 6 December 2005. Numerical simulations reveal amplified mountain waves that break both in the troposphere and in the stratosphere. At the surface, there are locally strong winds. Sensitivity studies indicate that horizontal resolution as high as 3 km is needed to reproduce the observed turbulence. It is suggested that real-time simulations at that resolution would improve aviation forecasts.

1 INTRODUCTION

Several studies indicate that Greenland may be able to generate very amplified and even breaking gravity waves (e.g. the FASTEX case reported Doyle et al. (2005) and Rögnvaldsson and Ólafsson (2003)). Incidents of strong turbulence over Greenland have been reported by commercial aircrafts, but to the knowledge of the authors of this paper, such cases have so far not been investigated. On 6 December 2005 a commercial aircraft flying at a high level encountered severe turbulence over South-Greenland. Such incidents have occurred before, but generally in westerly flow. Here, the 6 December case is simulated. The wave activity and the surface jets close to the tip of Greenland are explored.

2 OBSERVATIONAL DATA AND NUMERICAL SIMULATION

The observations are from a commercial aircraft, flying out of Iceland towards N-America. The aircraft experienced severe turbulence and very abrupt changes in wind speed over S-Greenland at about 200 hPa. There were neither any significant structural damages nor injuries on board. The flow is simulated with the numerical model MM5 (Grell et al. 1994), using the Eta PBL parameterization. Initial and boundary conditions are from the ECMWF. The vertical resolution is 40 levels and the horizontal resolutions are 9 km and 3 km. The topography of S-Greenland and the simulation domains are shown in Fig. 1.

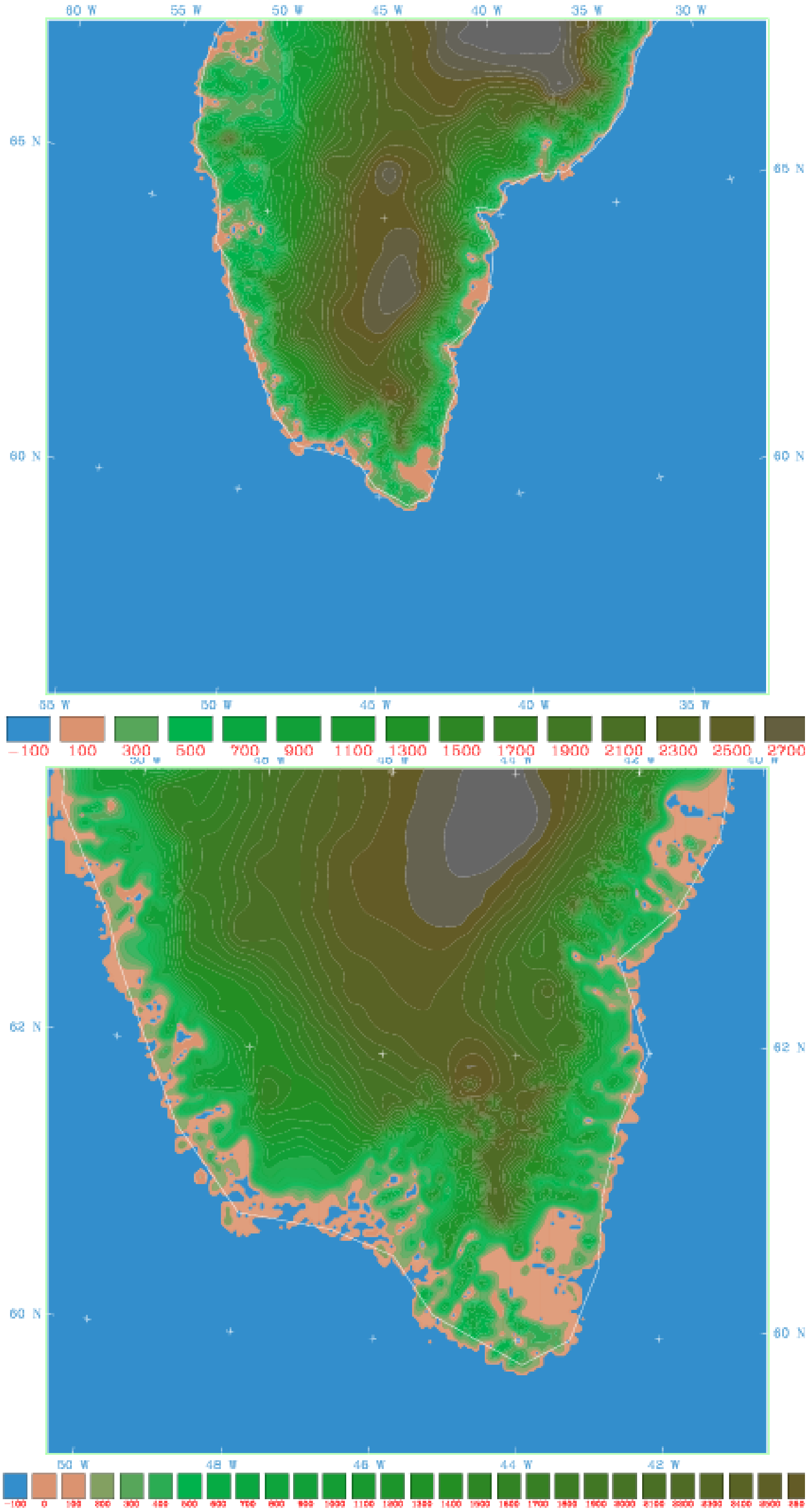

Figure 1. Topography (m) in the numerical simulations. Horizontal resolution 9 km (top) and 3 km (bottom).

3 RESULTS

Figure 2 shows a radiosounding from Narsarsuaq, S-Greenland at 12 UTC on 6 December 2005. The sounding shows strong easterly winds throughout most of the troposphere. At low levels, the airmass is conditionally unstable, but there is a stable layer above 650 hPa. In the stratosphere, there are weaker southwesterly winds. Figures 3 and 4 show the simulated flow at 200 hPa (close to the flight level) and a cross section along the low level flow for horizontal resolutions of 9 km and 3 km. There is indeed a pronounced wave activity throughout the troposphere. The steepness of the waves and the turbulence indicate breaking at middle tropospheric levels and also above the tropopause, where severe turbulence was observed by the aircraft. The stratospheric waves and the associated turbulence are greater and more realistic in the 3 km simulation than in the 9 km simulation. Figure 5 shows surface winds, mean sea level pressure and temperature at 925 hPa. There is a barrier jet at the east coast of Greenland and a corner wind downstream of the southernmost mountains. The strongest winds are found over Greenland, further to the north, below the amplified waves. Downstream of the strongest winds, there is a wake with weak winds.

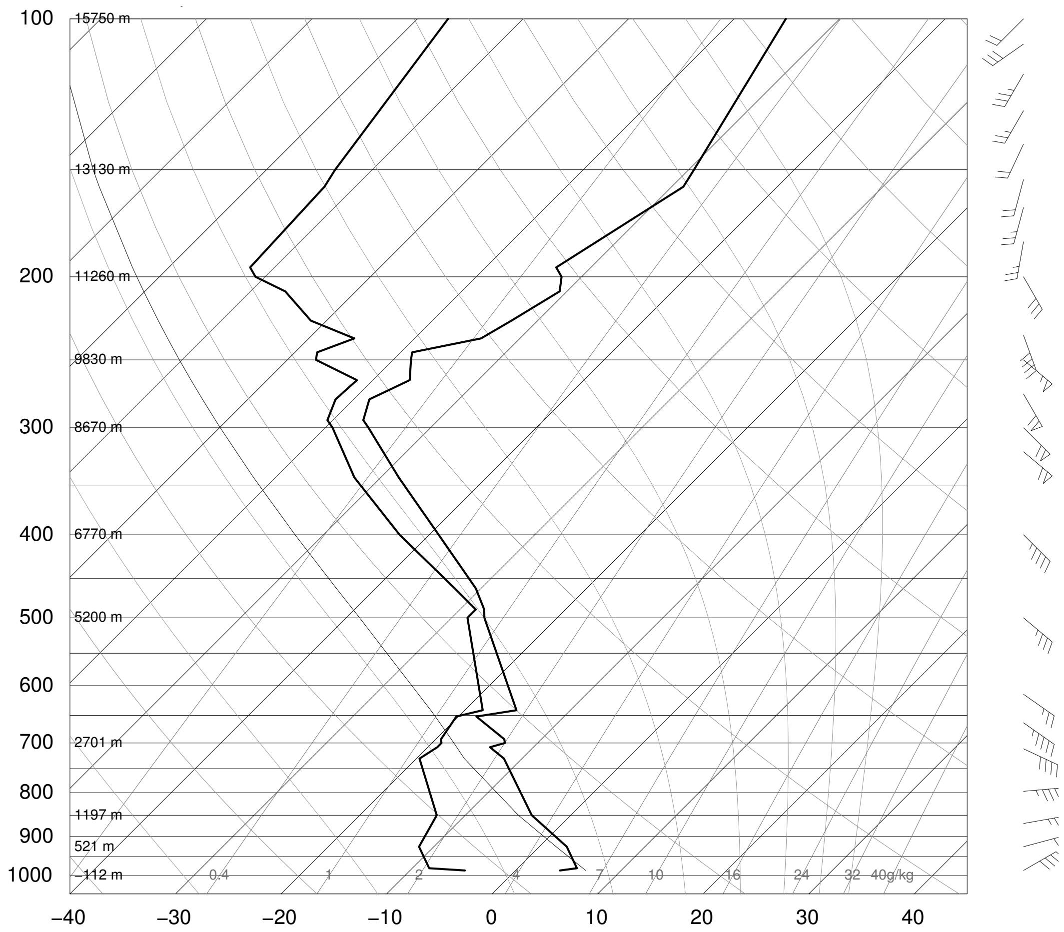

Figure 2. Radiosounding from Narsasuaq, South-Greenland at 12 UTC on 6 December 2005 (retrieved from the University of Wyoming, USA).

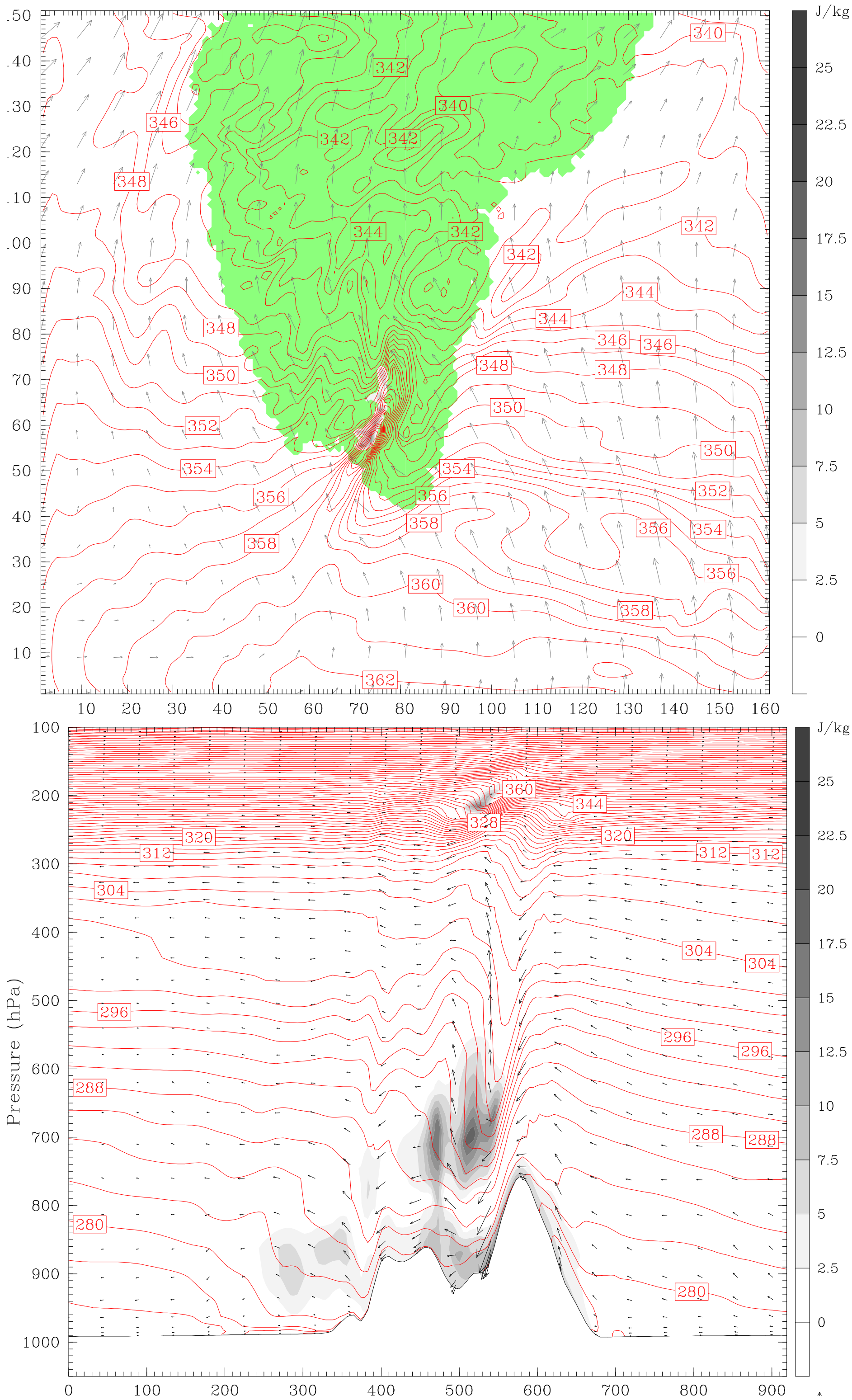

Figure 3. Potential temperature (K), turbulence (J/kg) and wind vectors at 200 hPa (top) and in a cross section (bottom) over S-Greenland along the flow. Horizontal resolution 9 km.

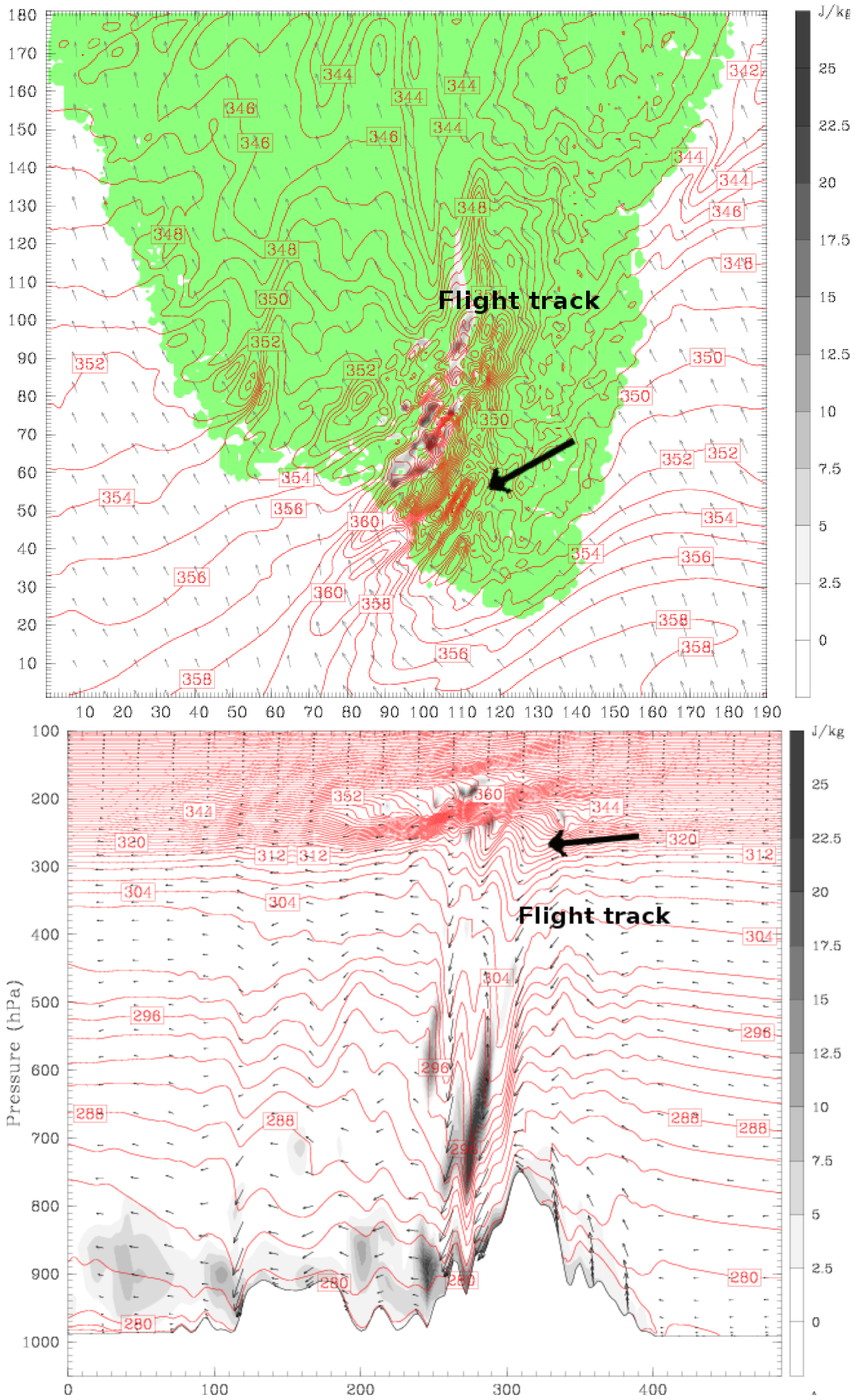

Figure 4. Potential temperature (K), turbulence (J/kg) and wind vectors at 200 hPa (top) and in a cross section (bottom) over S-Greenland along the flow. Horizontal resolution 3 km.

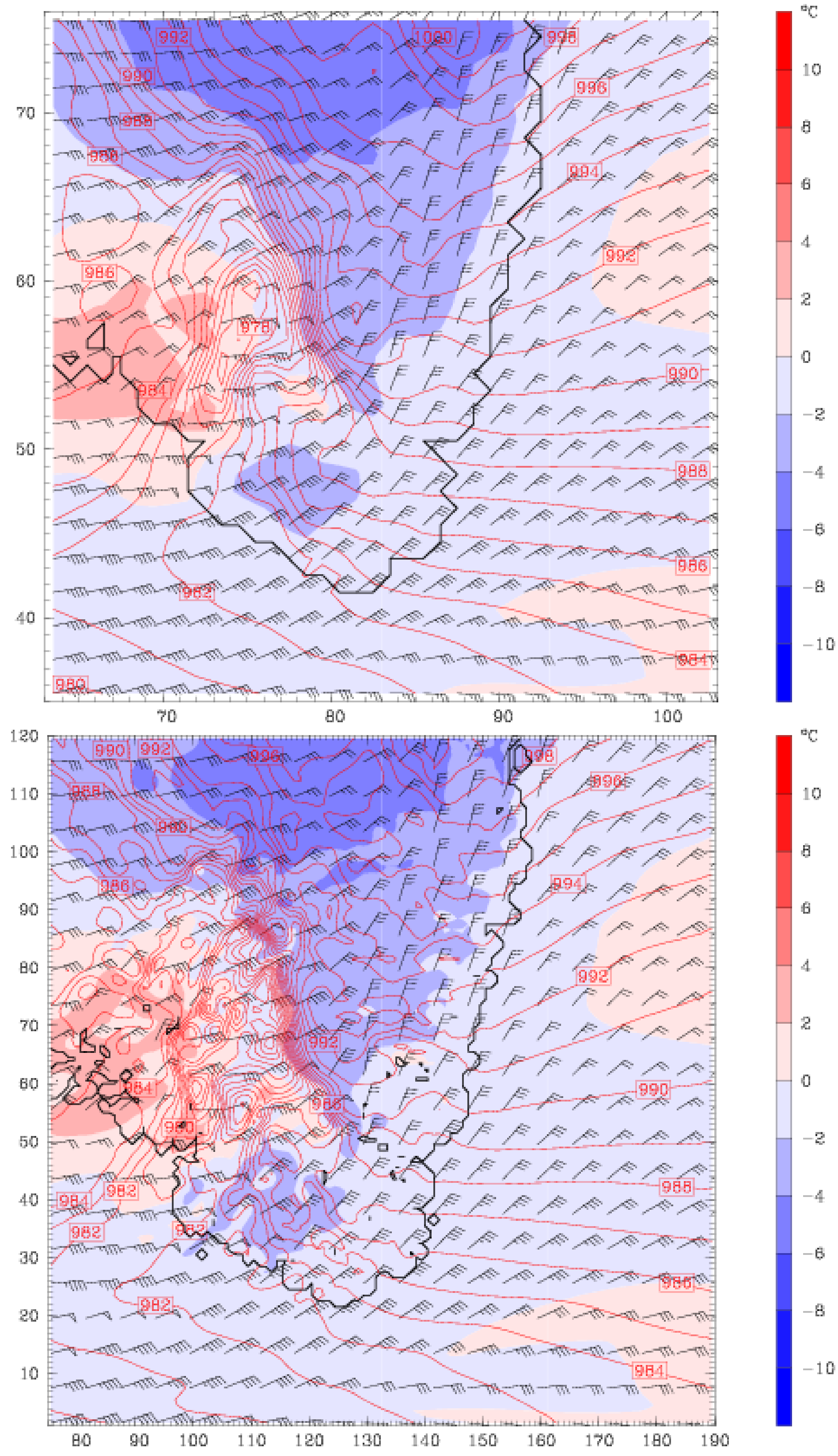

Figure 5. Temperature (K) at 925 hPa, mean sea level pressure (hPa) and wind barbs (one full wind-barb corresponds to 5 m/s) in a simulation with horizontal resolution 9 km (top) and 3 km (bottom).

4 DISCUSSION

The atmospheric conditions for mountain wave generation are quite good: strong low level winds perpendicular to the mountains and a stable layer not far from the top of the mountains. Weakening of the winds with height at middle tropospheric levels contribute to the breaking of the waves at these levels. In spite of tropospheric breaking, some of the wave energy is evidently able to penetrate up to the stratosphere, where the waves break. This is the first time to the knowledge of the authors of this paper that evidence is given of gravity wave breaking in easterly flow over Greenland. Strong easterly flow in this region of the world is in most cases associated with a reverse vertical windshear (e.g. Ólafsson and Ágústsson (2007)), which in many cases would inhibit the waves to propagate up to the stratosphere.

The low level (barrier) winds along the east coast of Greenland become increasingly ageostrophic as one moves to the south along the coast and there is only a very limited low level west-east temperature gradient to contribute to these winds. Both the shooting flow below the waves and the corner jet downstream of the southernmost part of the mountains are very much ageostrophic. These local winds that are generated around Greenland in easterly flows are well known to forecasters, but they have so far not been the object of many scientific studies apart from Moore and Renfrew (2005) (see Doyle and Shapiro (1999) for the westerly tip jet). This may change after the Greenland Flow Distortion Experiment (http://lgmacweb.env.uea.ac.uk/e046/research/gfdex).

5 CONCLUSIONS

Breaking of gravity waves over Greenland is possible in easterly flows and it can indeed be a hazard to aviation. Moving from 9 km horizontal resolution to 3 km increases the simulated breaking intensity and makes it more realistic at the intercontinental air traffic level in the lower stratosphere. This indicates strongly that aviation forecasts of turbulence in this region are likely to improve if they are based on high-resolution real-time simulations.

Acknowledgements

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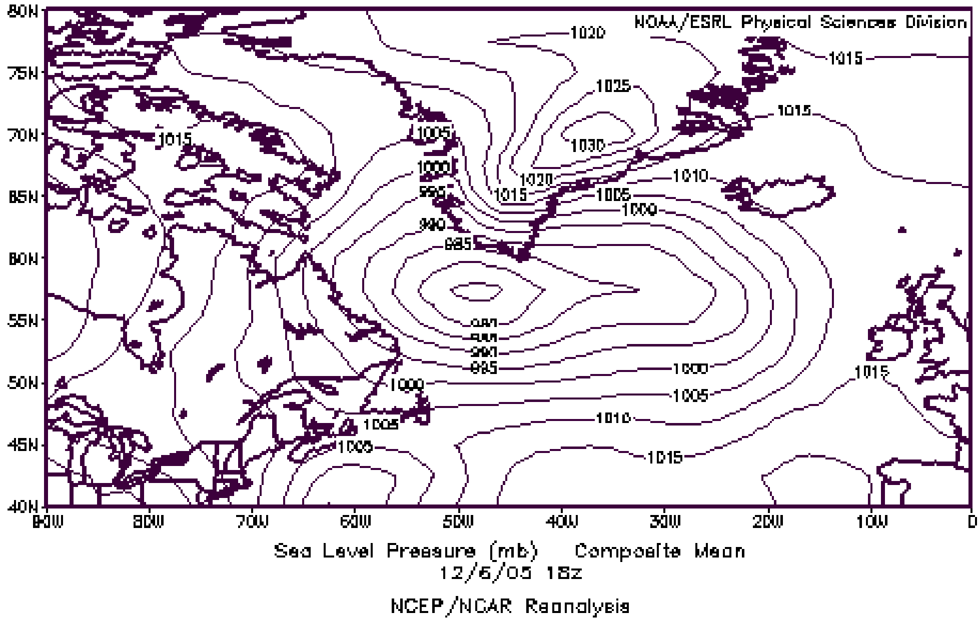
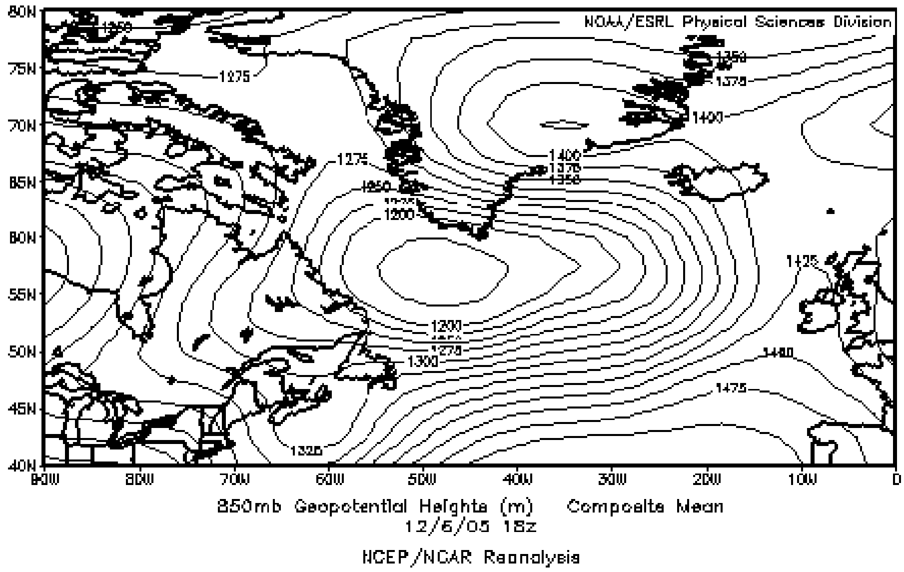
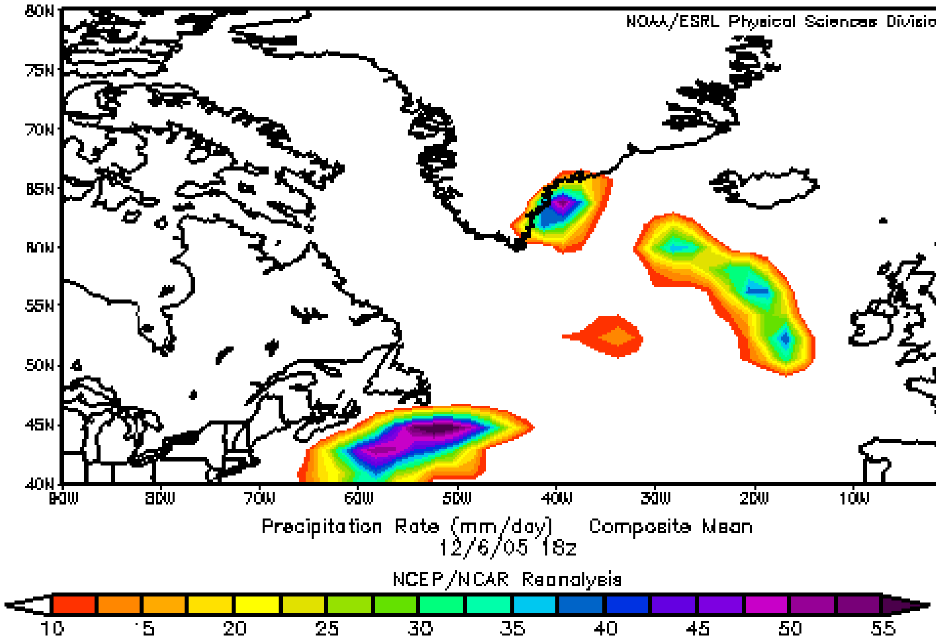
A APPENDIX – THE LARGE SCALE FLOW



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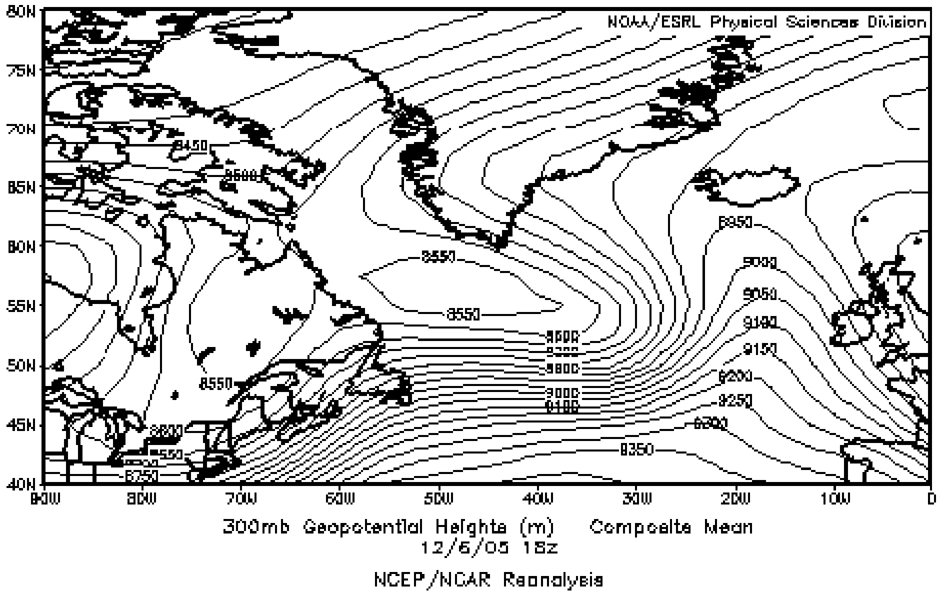
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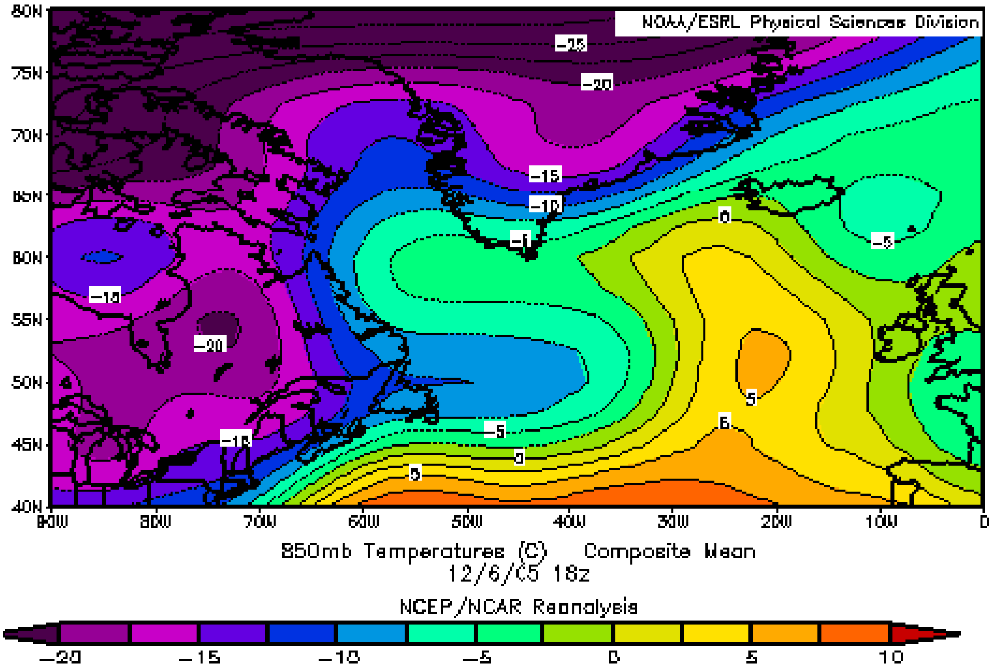
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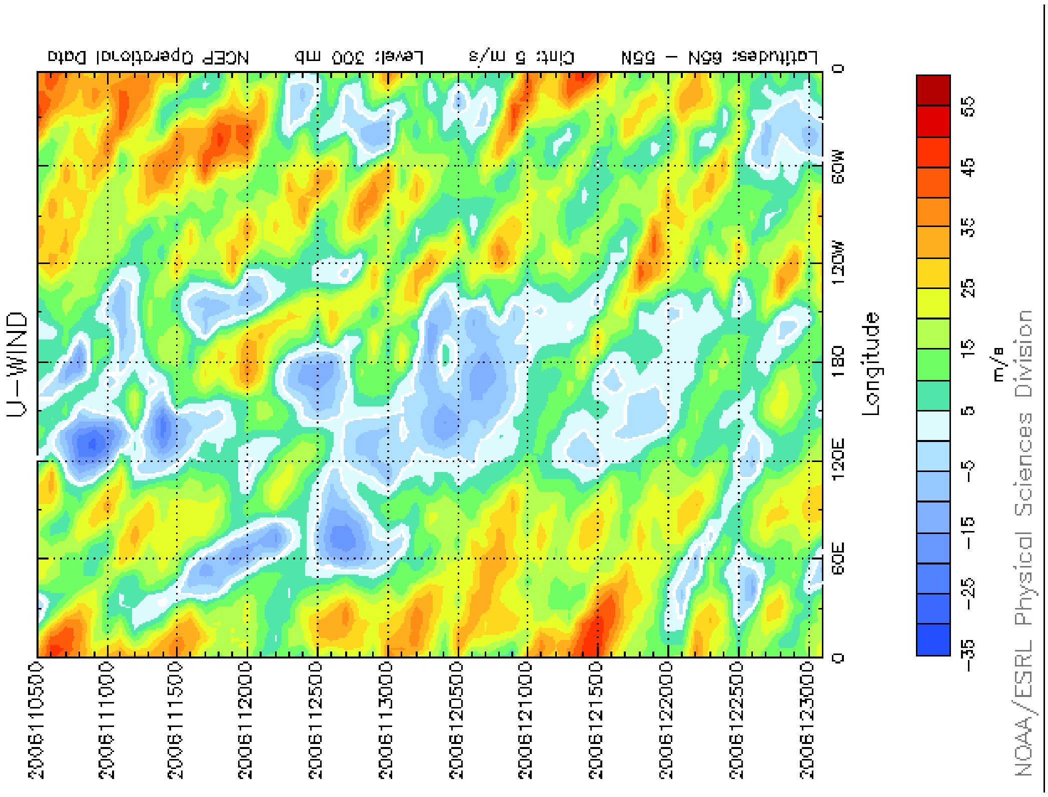
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FORECASTING WIND GUSTS IN COMPLEX TERRAIN

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Abstract: Wind gusts are calculated in a large collection of simulated atmospheric flows in complex terrain in Iceland. The gust method is based on a comparison of atmosperic stability and turbulent kinetic energy in the planetary boundary layer. The atmospheric data is a part of realtime numerical simulations used in forecasting in Iceland and is generated with the MM5 model at a horizontal resolution of 9 and 3 km, and in some cases 1 km. Initial and boundary conditions are from the ECMWF. The gust prediction method is implemented as post-processing within the IDL environment, into which the simulated MM5-data is imported using the mm5idl-package. The calculated gust strength is compared with wind gust observations from numerous automatic weather stations. The estimated gusts are strongly dependent on the quality of the simulated flow and are on average well captured when the mean winds are correctly simulated. Maximum gusts in downslope windstorms are however frequently underestimated. The error is presumably related to an inadequate simulation of the downstream surface winds which are also strongly underestimated in the windstorms. The method has previously been found to perform well in a corner wind, while here, wind gusts are successully reproduced upstream of mountains as well as in the mountains.

Keywords - *Gust forecasting, windstorms, complex terrain, Iceland*

1. INTRODUCTION

The greatest winds in windstorms are related to fluctuations in the wind speed at periods as short as a few seconds. These fluctuations are known as wind gusts and may easily exceed twice the mean wind speed in extreme weather events. The gusts are a manifestation of atmospheric turbulence which is primarily found in the atmospheric boundary layer (BL), but may also be found aloft, e.g. near upper level jets where it may be a danger to aviation. The turbulent motion is driven by high vertical wind shear and/or low static stability. Of importance for this study is the turbulence created in atmospheric flow in and above complex terrain. There is in fact strong evidence in the relevant literature, indicating that major gust events may be related to turbulence aloft, created by local convective instability in regions where gravity (buyoancy) waves break.

The strong gusts are one of the main causes of damage to structures and vegetation in extreme weather events. Several different systems to predict gusts have therefore been devised. Some are based on statistical methods, e.g. using empirical gust factors or an inspection of the vertical wind and stability profiles. Other methods are based on the parameterization of turbulence in numerical weather prediction models, such as the method of Brasseur (2001) which is employed here. The method is fully based on physical considerations and has been proven successful, both in studies in continental Europe as in Belŭsić and Klaić (2004) as well as during windstorms in Iceland (e.g. Ólafsson and Ágústsson 2007).

Wind gusts have been predicted in a large collection of simulations of atmospheric flow over Iceland. Here we focus on predicted gusts during a chosen period in a region in West-Iceland. Wind gust observations from numerous automatic weather stations in complex terrain, are compared with the predicted gusts. The next section discusses the methodology applied in the study, while in section 3 some the results of the gust prediction are discussed and compared to the available observational data. Section 4 summarized the most significant results.

2. METHODOLOGY

Brasseur (2001) proposes that strong surface gusts may be created by turbulent eddies that deflect air parcels flowing aloft in the boundary layer down to the surface (Fig. 1). Due to the general increase of wind speed with height and the short time span surface friction acts to decelerate the air parcels, they will be observed as a gusty wind at the surface. Here, the turbulent kinetic energy (TKE) is of primary importance for the creation of wind gusts and may be obtained from

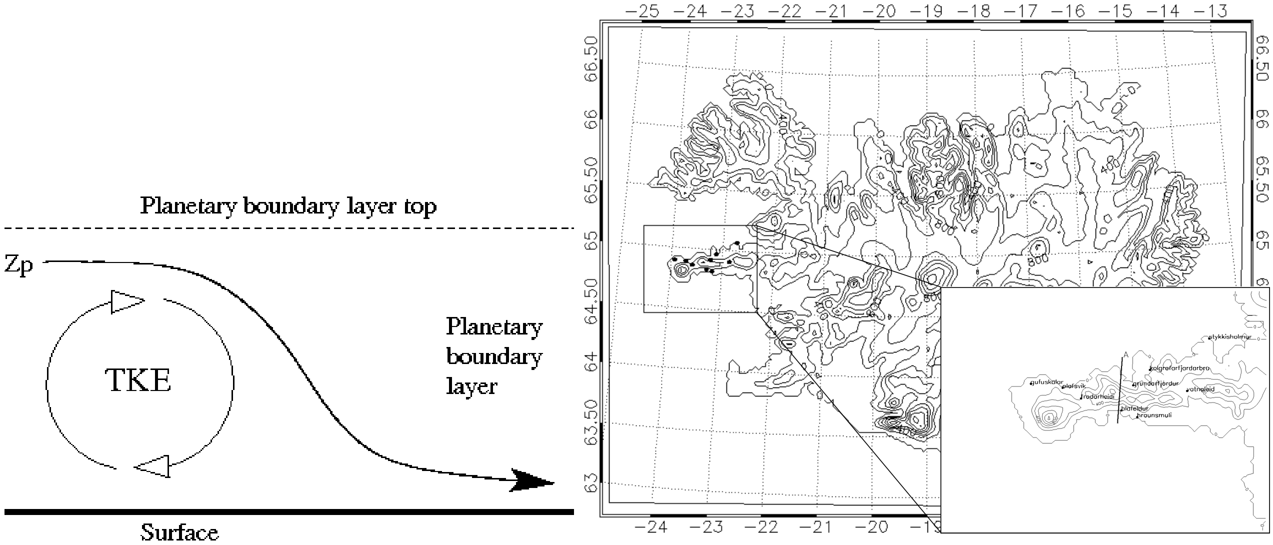

Figure 1. Left: The predicted gusts are created by turbulent eddies that deflect air from aloft to the surface. Right: The numerical domains with a horizontal resolution of 3 and 1 km as well as locations of chosen weather stations in the Snæfellsnes peninsula.

numerical models. In stable boundary layers, the atmospheric stability (buoyancy forces) oppose the vertical deflection of air parcels, while in unstable layers it enhances the turbulence. The method is mathematically expressed as

$$\frac{1}{z_p}\int_0^{z_p} E(z)\,\mathrm{d}z \geq \int_0^{z_p} \mathrm{g}\,\frac{\Delta\theta_v(z)}{\Theta_v(z)}\,\mathrm{d}z, \tag{1}$$

where z_p, $E(z)$, Θ_v and $\Delta\theta_v$ are respectively the height of the parcel, the TKE, the virtual potential temperature and its variation for the parcel when deflected to the surface. The estimated wind gust, f_g, is chosen as the maximum wind speed for all parcels which satisfy (1) in the boundary layer but since turbulence is generally weak above the boundary layer, air parcels originating there are not expected to be able to reach the surface of the earth.

In addition to the estimated gust strength, the method gives a bounding interval for the estimated gusts. The upper bound, $f_{g,max}$, is taken as the maximum wind speed in the PBL. The lower bound, $f_{g,min}$ is found by using the vertical component of the local turbulence, as opposed to the mean TKE in the left hand side of (1). An in depth explanation of the method is given by Brasseur (2001).

The wind gusts are predicted in atmospheric data which is a part of realtime numerical simulations used in forecasting in Iceland, e.g. at the Icelandic Meteorological Office. The data includes a large number of different flow regimes and here we choose to present results for a period of approx. 1 month, starting on 14 February 2007, from the Snæfellsnes peninsula in West-Iceland. The data is generated with the MM5 model (Grell et al. 1994), with 40 levels in the vertical and a horizontal resolution of 9 and 3 km, and in some cases 1 km (Fig. 1). The high resolution is necessary to reproduce the flow in complex terrain, e.g. gravity wave activity and mechanically induced turbulence where the flow interacts with the topography. Initial and boundary conditions are from the ECMWF. The gust prediction method is implemented as post-processing within the IDL environment, into which the simulated MM5-data is imported using the mm5idl-package (http://www.os.is/∼or/rev/mm5idl/).

The calculated gust strength is compared with wind gust observations from numerous automatic weather stations in complex terrain in Iceland (see Fig. 1 for station locations). The weather stations belong to Veðurstofa Íslands (The Icelandic Meteorological Office) and Vegagerðin (The Public Roads Authority). Observations include the 10 minute mean wind and 3 second maximum wind gusts. The wind is observed at either 10 m or approx. 7 m above the ground. The difference in observation heights is expected to be irrelevant due to the non-local nature of the wind gusts.

3. RESULTS

The period from approx. 14 February to 14 March 2007 is characterized by several northerly windstorms in the Snæfellsnes peninsula, with observed mean winds exceeding 30 m/s and gusts as great as 50 m/s. In between the windstorms are periods of far weaker winds which are often south- or easterly. The data presented in Fig. 2 includes observations from the Bláfeldur automatic station on the southern side of the Snæfellsnes peninsula and predicted gusts at the 21 and 24 hour forecast time. The horizontal grid of the numerical domain is of 3 km. It is apparent that on average, the predicted gusts

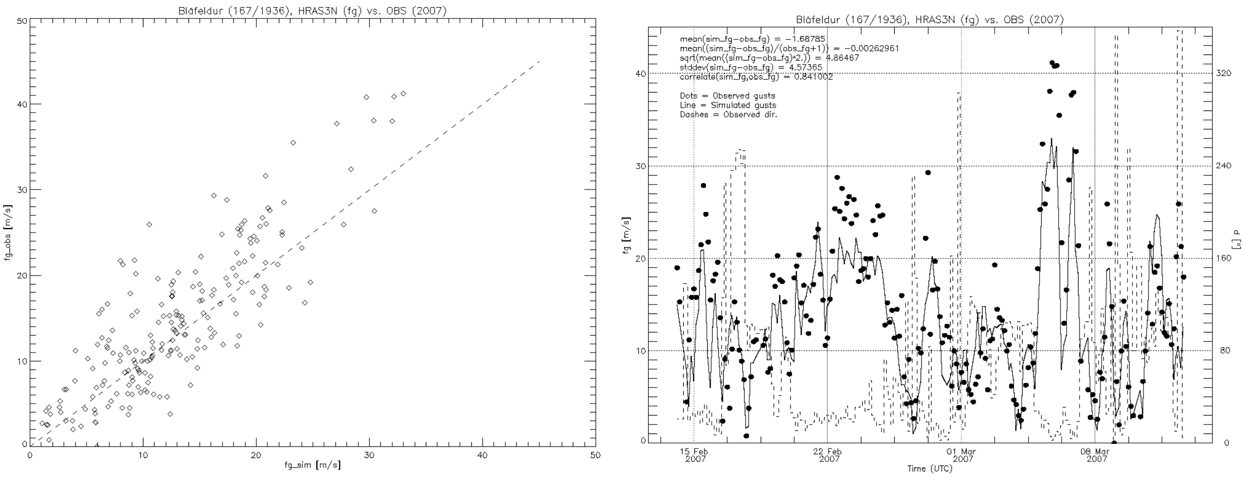

Figure 2. Observed and simulated wind gusts f_g, in a 3 km grid, at the Bláfeldur station from 14 February to 14 March 2007.

correlate well with the observed gusts at Bláfeldur and the temporal behaviour is well captured. The greatest errors are in northerly winds, when the flow is nearly perpendicular to the peninsula and has to pass over it. At these time, the winds are on average strong and gusty. The strongest winds are observed on 5–6 March, during severe northerly windstorms, when an accurate gust estimate is in fact most important. Somewhat similar results are seen at other stations in the peninsula, although the northerly windstorms and the associated errors are far less prominent in stations located on the northern side of the peninsula.

On the evening of 5 March, a surface low was located southeast of Iceland, with the centre near the Faroe Islands. There was a high over Greenland and relatively high pressure gradients over western Iceland and the Denmark strait, causing the strong northeasterly winds. Fig. 3 shows the predicted gust strength in the Snæfellsnes peninsula at 22 UTC on the evening of 5 March. The horizontal resolution is 1 km. The predicted gusts are strongest, as expected, everywhere on the southern side of the peninsula with a maximum near the locations of Bláfeldur and Hraunsmúli. Much weaker winds and gusts are predicted in the upstream decelerated flow. The surface winds are on average reasonably simulated on the northern side, e.g. at Stykkishólmur, Kolgrafarfjarðarbrú and Grundarfjörður (Tab. 1). The observed gusts are mostly within or very near the bounds of the predicted gusts and the temporal behaviour of the observed gusts is well captured. However, the atmospheric model only manages to capture the mean winds correctly on the southern side during the lull in the storm between 5 and 6 March. During the maximum of the windstorms, the mean winds are greatly underestimated at several stations, e.g. at the downstream stations of Bláfeldur and Hraunsmúli, while there are however stations where the performance is much better, e.g. at the Vatnaleið station in the centre of the eastern part of the peninsula (Tab. 1). The observed gusts are greatly underestimated during the storms, which is as expected since the gust prediction method is strongly dependent on the simulated mean winds which are strongly underestimated.

Table 1: Observed and simulated (with a horizontal resolution of 1 km) mean winds and gusts [m/s] at chosen stations at 22 UTC on 5 March 2007.

Station	$f_{10,obs}$	$f_{10,sim}$	$f_{g,obs}$	$f_{g,sim}$
Grundarfjörður	13.2	8.8	21.5	27.2
Kolgrafarfjarðarbrú	15.9	16.3	25.8	24.8
Stykkishólmur	10.2	12.9	18.7	20.7
Bláfeldur	32.1	19.6	40.8	34.1
Hraunsmúli	29.2	17.9	49.5	30.8
Vatnaleið	16.9	12.1	28.8	24.2

A more in depth study of the windstorms on 5 and 6 March reveals breaking waves above the Snæfellsnes peninsula during the northerly windstorms (Fig. 3). The conditions for wave breaking are favourable, strong winds at mountain top level and a reverse wind shear with a minimum in wind speed above 500 hPa. There is a large concentration of TKE in the region of the breaking waves and accelerated flow below the breaking waves and above the leeside slopes of the peninsula, presumably causing the observed downslope windstorms, e.g. at the Bláfeldur and Hraunsmúli stations.

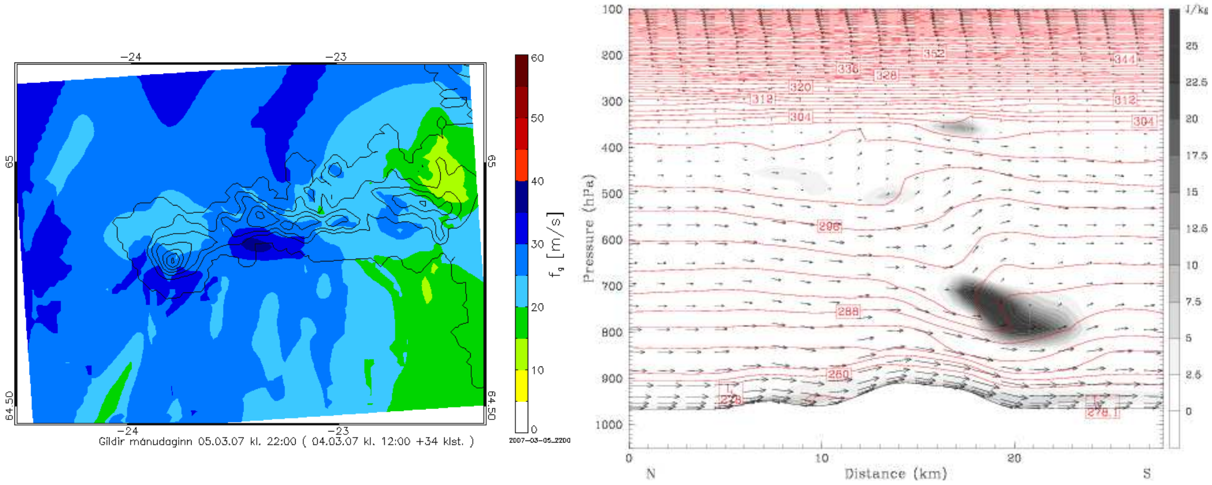

Figure 3. Left: Simulated wind gusts f_g on the Snæfellsnes peninsula. Right: Section A (see location in Fig. 1) from north to south across the Snæfellsnes peninsula. Shown are isolines of potential temperature, wind speed vectors and turbulent kinetic energy. Both panels are valid at 22 UTC on 5 March 2007 with a horizontal resolution of 1 km.

4. CONCLUSIONS

Wind gusts have been parameterized in a collection of atmospheric simulations of flow over Iceland. Here we discuss the predicted gusts during a period of one month, which includes severe windstorms, in the Snæfellsnes peninsula in West-Iceland.

The results of this study are consistent with previous studies on the use of the gust prediction method, e.g. Ólafsson and Ágústsson (2007). The quality of the predicted gusts is strongly correlated with the ability of the model to correctly simulate the mean surface winds. Where the mean surface winds are correctly captured, the predicted gusts are on average in reasonable agreement with the observations. The greatest errors in the gust prediction include the underestimation of the predicted gusts during severe downslope windstorms. This is presumably to related to the inadequate simulation of the downstream surface winds by the atmospheric model and the BL scheme. We feel that further tests with different BL schemes and atmospheric models, e.g. the WRF-model, are needed. Furthermore, observations of the key atmospheric fields in the BL, including the turbulence, would be invaluable.

However, the results are of the study indicate that gusts can be successfully predicted in the complex terrain in Iceland. This is of special interest in the context of operational weather forecasting where gust forecasts may give valueable information, for example regarding road safety and possible damage to structures during severe windstorms.

Acknowledgements

This study is partly supported by the ongoing RÁV-project, RANNÍS (The Icelandic Centre for Research), the Icelandic Research Fund for graduate students, Vegagerðin (The Public Roads Authority) and Landsvirkjun (the National power company). Observational data is from Veðurstofa Íslands (The Icelandic Meteorological Office) and Vegagerðin.

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DOWNSLOPE WINDSTORMS IN ICELAND WRF/MM5 MODEL COMPARISON - II

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What, why and how?

Here, we study recent downslope windstorms in in northerly flow in the Snæfellsnes peninsula. The storms are simulated with the MM5 as well as the AR-WRF numerical models. The models are initiated with two different data sets (GFS and ECMWF operational analysis) and the sensitivity of the simulated fields and dynamics to different microphysics and parameterization of turbulent mixing in the PBL is tested. Also, the ETA boundary layer scheme is compared to a new 2-equation version of the same scheme. Ground observations of temperature and wind from automatic weather stations are used for verification.

The results

The WRF-model is in general more accurate during the windstorm, especially when forced with GFS-analysis. The far better performance with the operational GFS-analysis is presumably related to the greater number of pressure levels than from the EMCWF. However, this study is not conclusive and more observations from aloft would be beneficial. Contrary to a recent study (Rögnvaldsson et al. 2007), there is surprisingly little difference in the simulated surface winds and temperature when different microphysics schemes are applied in the WRF-model. This may be partly related to the size of the upstream mountain, which is far smaller in the current case, or the upstream conditions, e.g. atmospheric stability and hydrometeor species. There is greater dependence on the choice of PBL-scheme in the WRF-model than in MM5, with more fluctuations in the surface fields in the 2-equation PBL-scheme in WRF. However, the schemes perform similarily in both models which is indicative that the 2-equation scheme is a valid method for the parameterization of the TKE. Further tests and simulations are needed and will be addressed in the coming studies.

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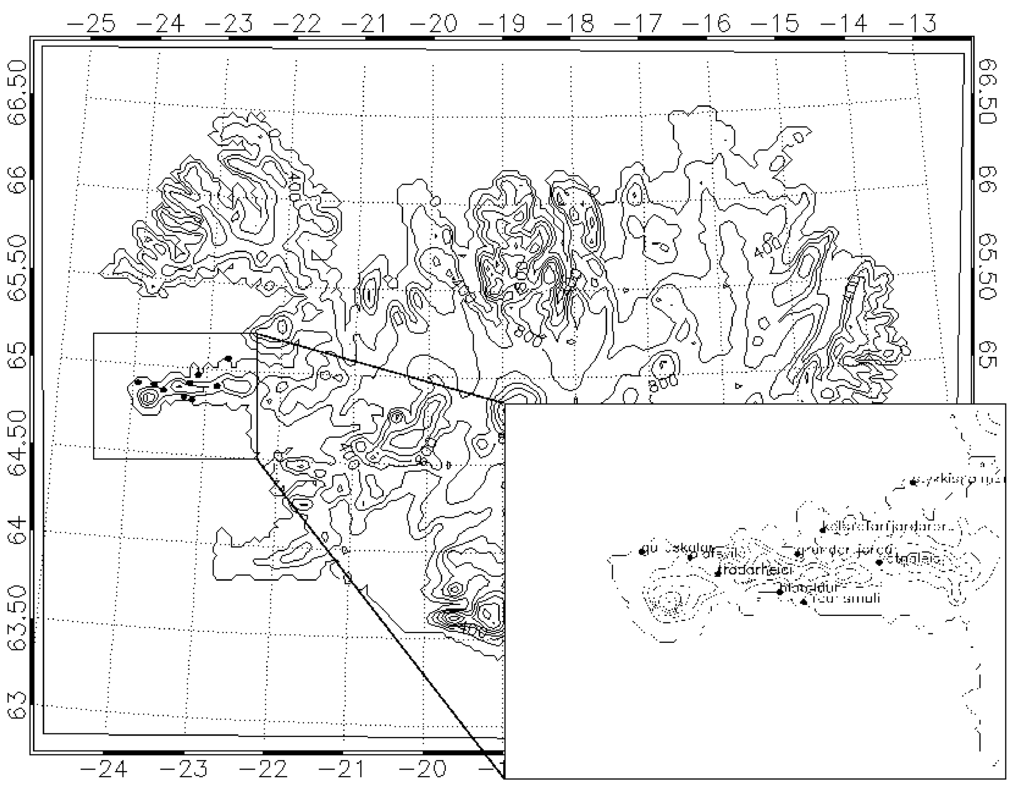
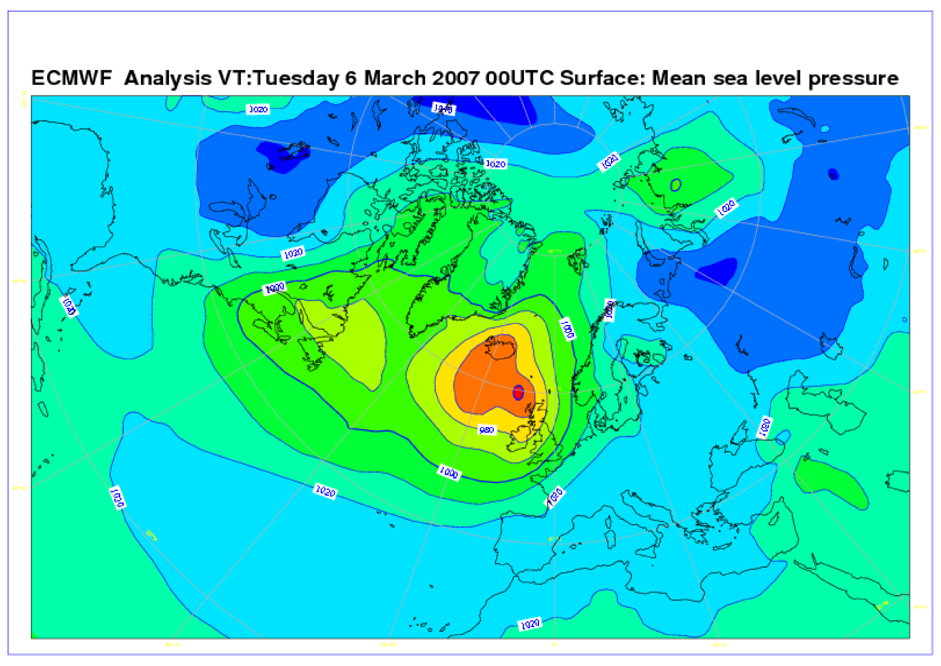


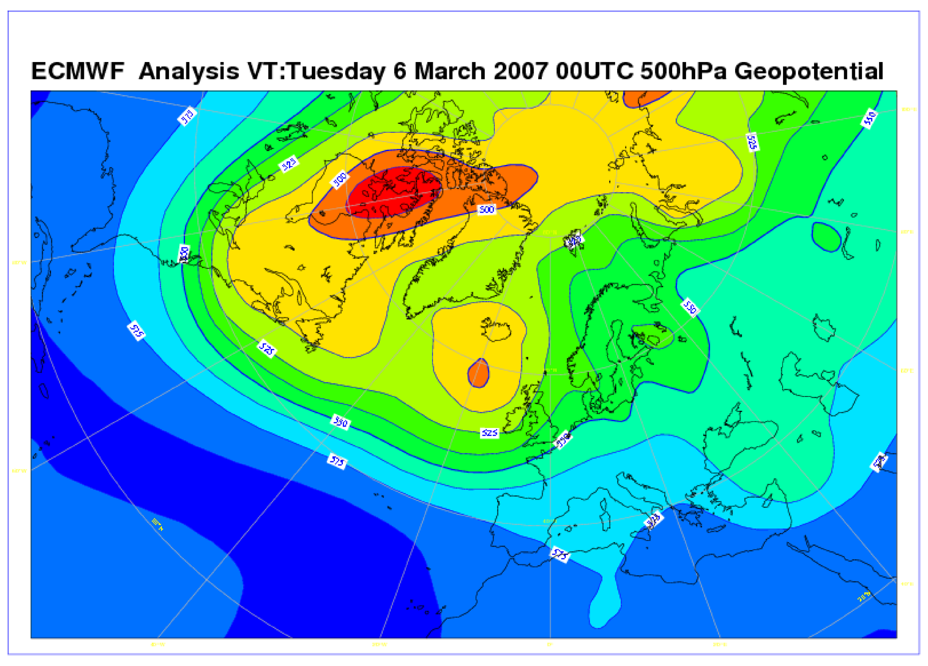
The numerical domains with a resolution of 3 and 1 km as well as station locations. Terrain contours with a 200 m interval.

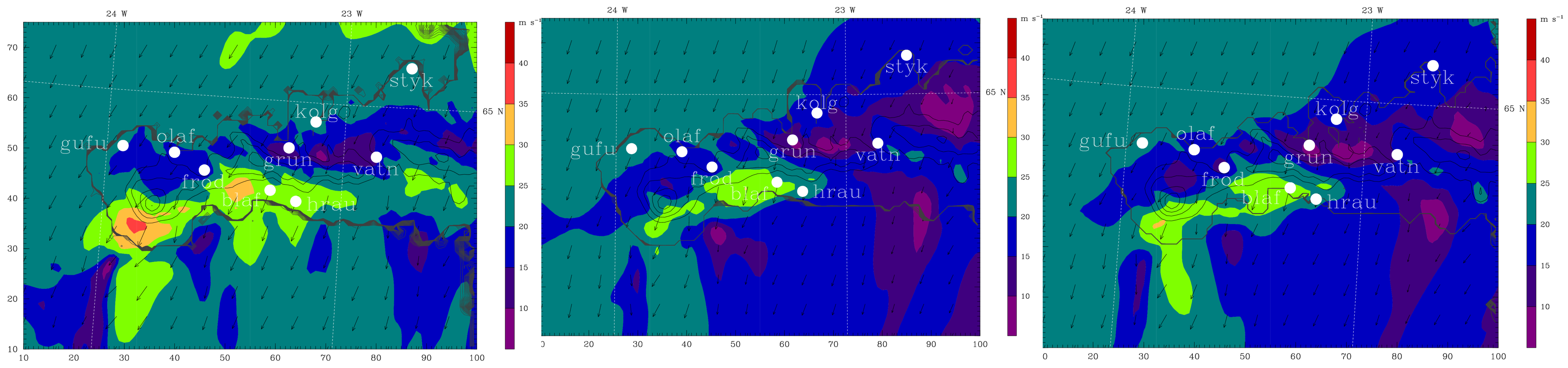
View towards east over the Snæfellsnes peninsula. The average mountain height is approx. 800 m while Mt. Snæfellsjökull in the front is 1446 m.



The mean sea level pressure [hPa] (left) and geopotential height [m] of the 500 hPa level (right), according to ECMWF-analysis.

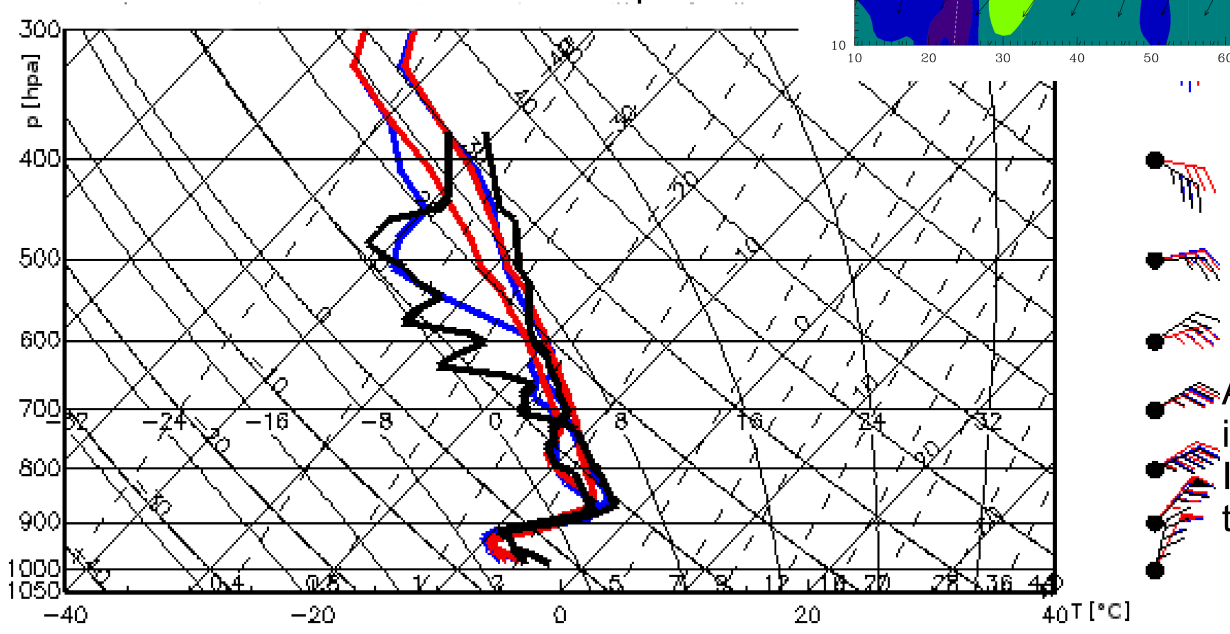
There is a surface low over Iceland and the storms are related to a strong E-W pressure gradient across West-Iceland. Aloft, there is a relatively flat and broad depression.





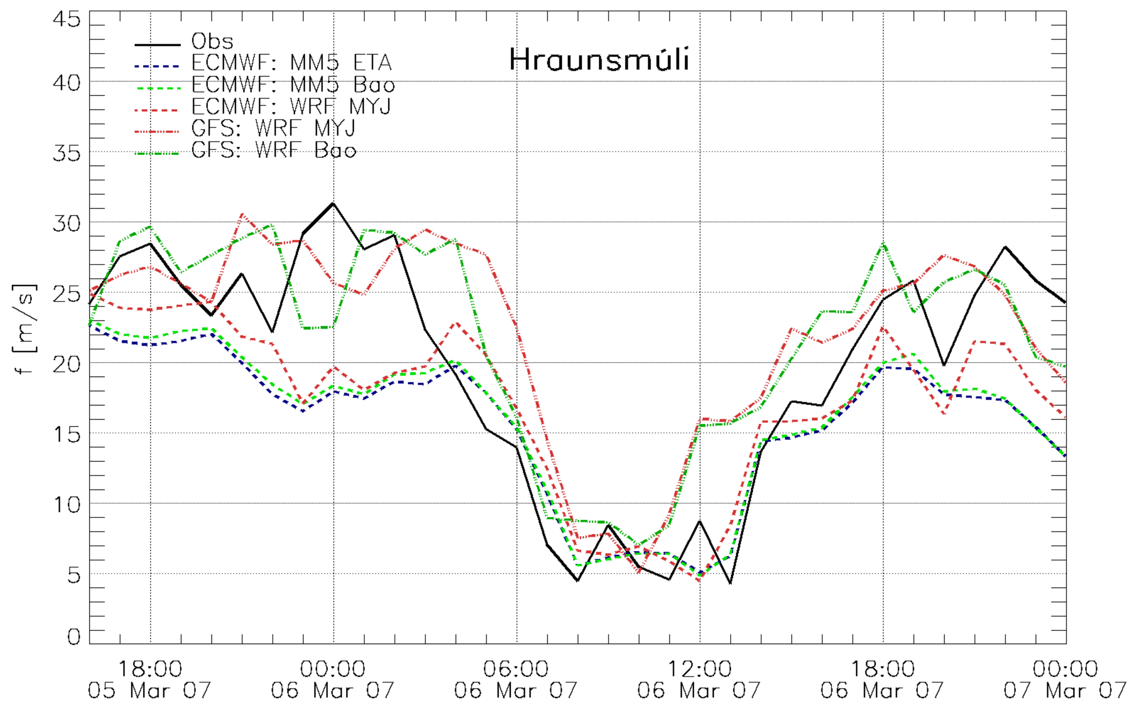
The simulated surface wind [m/s] at a resolution of 1 km at 00 UTC on 6 March, with the ETA-scheme, in AR-WRF with GFS-analysis (left) and ECMWF-analysis (middle), as well as in MM5 with ECMWF-analysis (right). Also shown are automatic observation locations.

The wind field is realistically simulated with both GFS- and ECMWF-data. There is a more localized deceleration of the impinging flow and leeside-speedup with the AR-WRF and GFS-data, while both models and ECMWF-data give somewhat smoother fields.



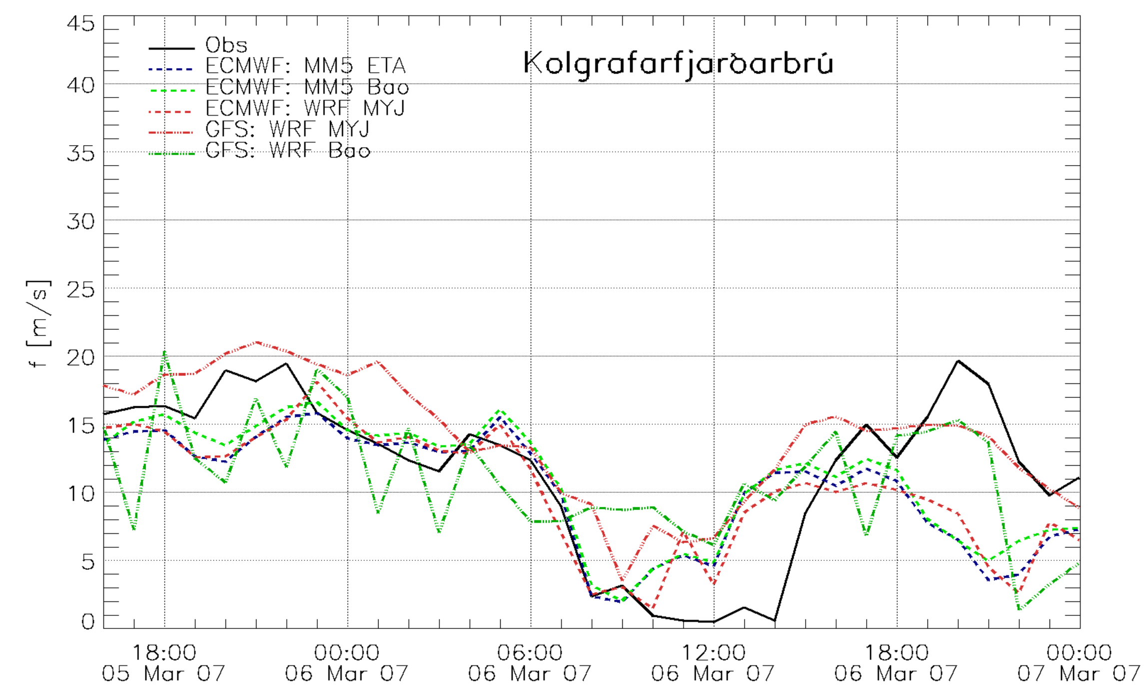
A sounding (black) from the recent GFDex-project indicates that the conditions upstream of Northwest-Iceland are more accurate in the GFS-analysis (blue) than in the ECMWF-analysis (red). (http://lgmacweb.env.uea.ac.uk/e046/research/gfdex/)

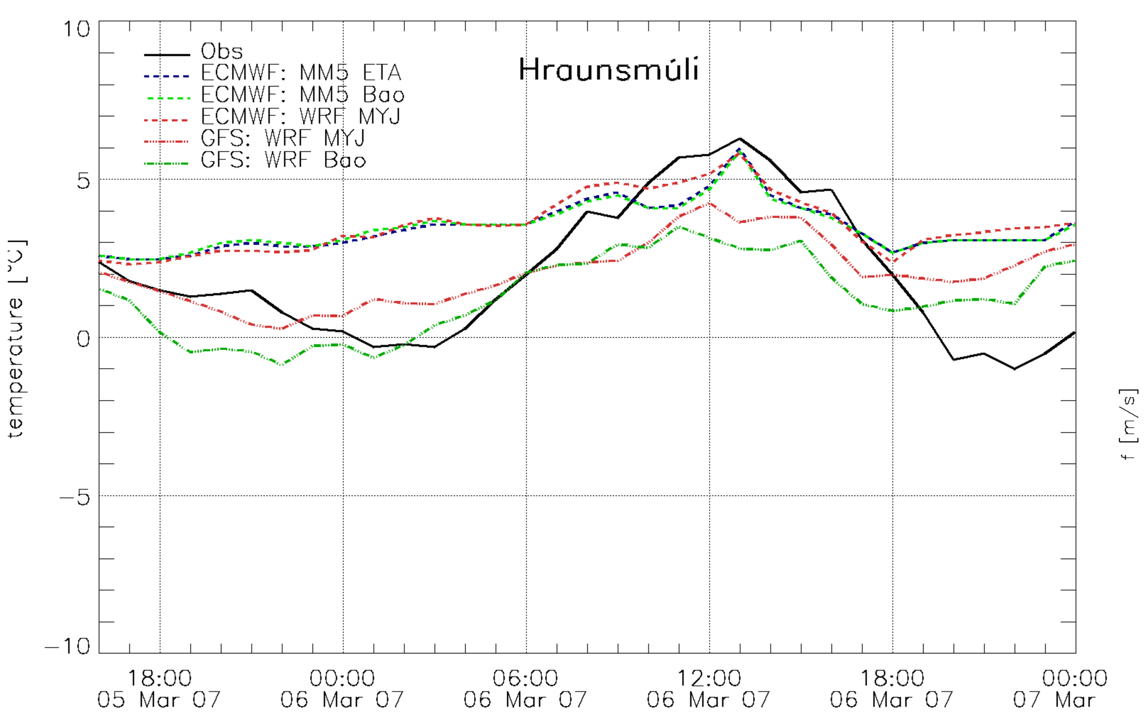
Acknowledgements: This work is part of the ongoing RÁV-project which is partly funded by Rannsóknasjóður Íslands (the Icelandic Research Fund).



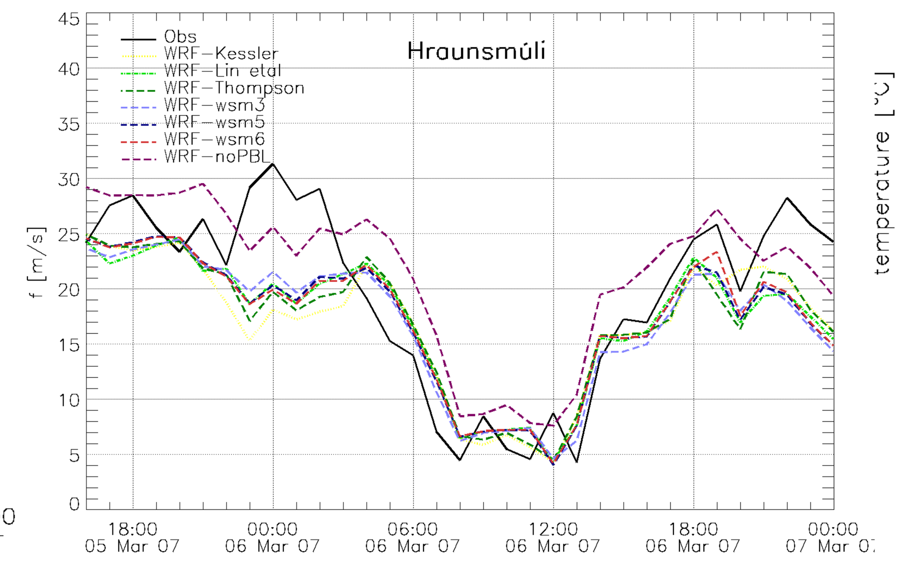
The observed and simulated surface wind [m/s] (above) and temperature [°C] (below), at a horizontal resolution of 1 km with different model setup. Downslope at Hraunsmúli (left) and upstream at Kolgrafarfjarðarbrú (right).

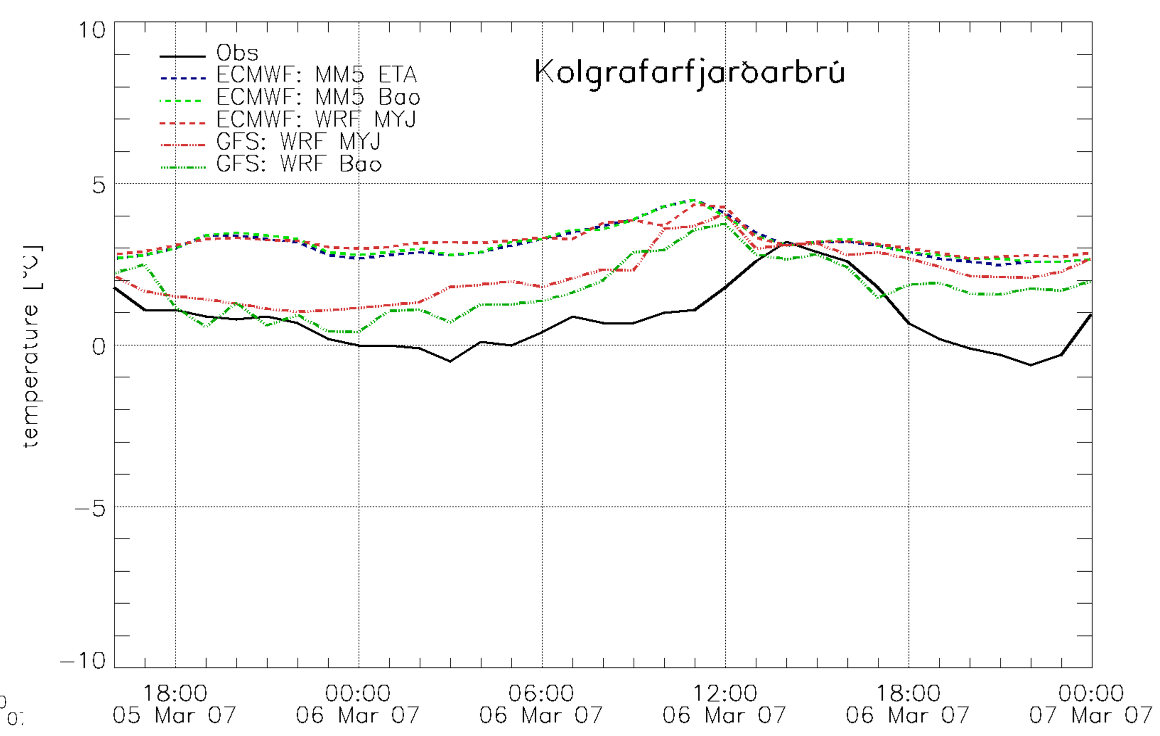
The AR-WRF with GFS-data tends to perform best. There is less difference between the simulated wind upstream than downslope. The far stronger and gustier downstream winds are found to be related to gravity wave activity aloft.





The simulated surface wind [m/s] at Hraunsmúli at a horizontal resolution of 1 km with various moisture-schemes in AR-WRF.





DOWNSLOPE WINDSTORM IN ICELAND – WRF/MM5 MODEL COMPARISON-I

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Abstract: A severe windstorm downstream of Mnt. Öræfajökull in Southeast Iceland is simulated on a grid of 1 km horizontal resolution by using the PSU/NCAR MM5 model and the Advanced Research WRF model. Both models are run with a new, two equation planetary boundary layer (PBL) scheme as well as the ETA/MYJ PBL schemes. Initial and boundary conditions for the simulations are derived from the European Centre for Medium–Range Weather Forecasts (ECMWF) analysis. The MM5 model is first run on 9 and 3 km resolution using two–way nesting. Then, the output from the 3 km MM5 domain are used to initialise and drive both the 1 km MM5 and WRF simulations. Both models capture gravity–wave breaking over Mnt. Öræfajökull, while the vertical structure of the lee wave differs between the two models and the two PBL schemes. The WRF simulated downslope winds, using the MYJ PBL scheme, are in good agreement with the strength of the observed downslope windstorm, with the maximum wind speed as great as 30 ms^{-1}, whilst using the new two equation scheme surface winds only reach about 20 ms^{-1}. On the contrary, the MM5 simulated surface winds, with the new two equation model, are in better agreement to observations than when using the ETA scheme. Surface winds reach 22 ms^{-1} when using the two equation model whilst the winds in the ETA simulation only reach about 17 ms^{-1}. The simulated surface temperature in the WRF simulations is also closer to the observations than the MM5 simulations.

Keywords *- Model comparison, PBL scheme comparison, MM5, AR–WRF, Iceland, downslope windstorm*

1. INTRODUCTION

The climate and weather of Iceland are largely governed by the interaction of orography and extra–tropical cyclones because Iceland is located in the North Atlantic storm track. As a result of this interaction, downslope windstorms are quite common. Research on Icelandic downslope windstorms was very limited until a recent study by Ólafsson and Hálfdán Ágústsson (2007) (hereafter ÓÁ–07), in which a severe downslope windstorm that hit Freysnes, Southeast Iceland, in the morning of 16 September 2004 was investigated by utilizing a numerical weather prediction model. In this study, four simulations are carried out and compared for the same event as studied in ÓÁ–07 by using two mesoscale models: V3–7–3 of MM5 (Grell et al. 1994) and the Advanced Research WRF model (Skamarock et al. 2005) and two different PBL schemes, the current ETA/MYJ planetary boundary layer model and a new two equation model (Bao et al. 2007, NCAR Tech. Note, in print). The output from the 3 km domain of the simulation presented in ÓÁ–07 is used to initialise and drive the two models on a grid of 1 km horizontal resolution and 39 vertical layers with the model top at 100 hPa. Both the MM5 and WRF models are configured in as similar way as possible. The objective of this study is to investigate the differences in the simulated dynamics of the downslope windstorm that are caused by the differences in the numerics of the two models. Comparisons of the four simulations are made using observed surface winds, temperature and precipitation. This paper is structured as follows: In the next section we descripe the synoptic overview and list the available observational data in the area. The results are presented in section 3, followed by concluding remarks.

2. SYNOPTIC OVERVIEW AND AVAILABLE OBSERVATIONAL DATA

Figure 1 shows the mean sea level pressure, the geopotential height at 500 hPa and the temperature at 850 hPa at the time when windgusts greater than 50 ms^{-1} were observed at the Skaftafell and Öræfi weather stations (see Fig. 2 for location of the stations). At the surface, the geostrophic winds are from the ESE, while over land the surface winds are from the ENE or NE. At 500 hPa, the flow is relatively weak (20–25 ms^{-1}) and the wind direction is from the SSE. There is a sector of warm air at 850 hPa stretching from Ireland towards S–Iceland. In the early morning of 16 September, the observed 2–meter temperature at Skaftafell exceeds 15°C which is about 7°C above the seasonal average. The geostrophic wind at the surface is greater than 30 ms^{-1} and there is a directional and a reverse (negative) vertical wind shear in the lower part of the troposphere. Figure 2 shows the domain setup of the MM5 and WRF simulations as well as the location of automatic meteorological stations.

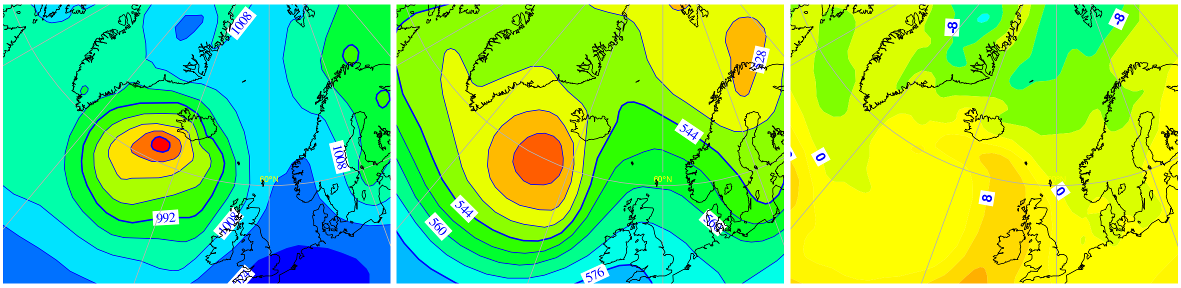

Figure 1: Mean sea level pressure [hPa] (left), geopotential height at 500 hPa [m] (middle) and temperature at 850 hPa [°C] (right) on 16 September 2004 at 06 UTC. Based on the operational analysis provided by the ECMWF.

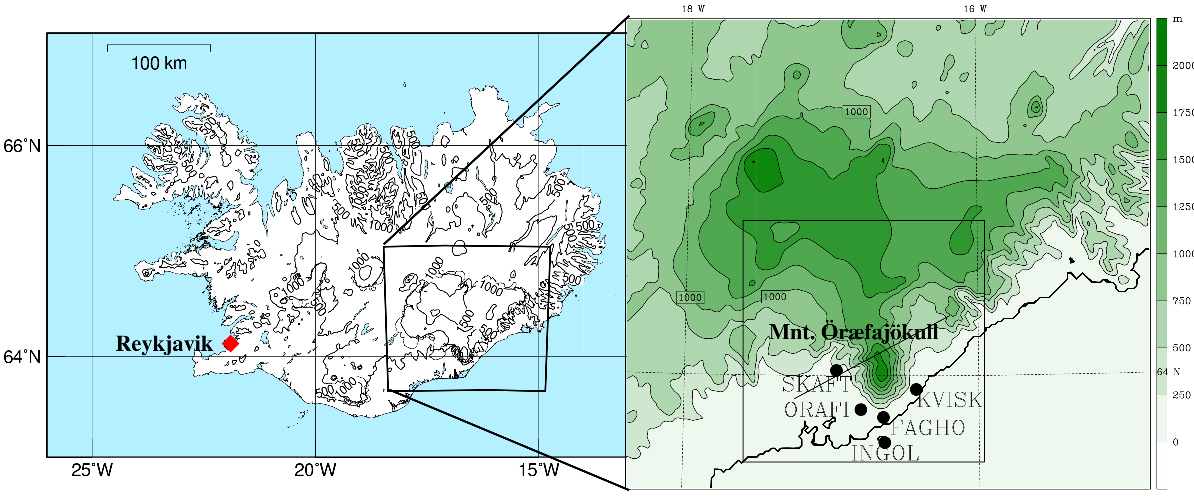

Figure 2: Domain setup and location of observational sites. The box on the right hand side shows the region of interest around Mnt. Öræfajökull.

These are Skaftafell (SKAFT), Öræfi (ORAFI), Ingólfshöfði (INGOL), Fagurhólsmýri (FAGHO) and Kvísker (KVISK). Surface wind speed and direction, gusts and temperature are all measured at these stations. At stations SKAFT, FAGHO and KVISK, accumulated precipitation is measured once to twice daily. The straight line crossing Mnt. Öræfajökull shows the location of the cross sections shown in Fig. 6.

Table 1: Observed and simulated accumulated precipitation [mm], between 15 September, 18 UTC and 16 September, 09 UTC, at stations Skaftafell (SKAFT), Fagurhólsmýri (FAGHO) and Kvísker (KVISK).

Precip	**Observed**	**MM5**		**AR–WRF**	
		ETA	2–eq	MYJ	2–eq
SKAFT	0.0	0.0	0.0	0.8	1.2
FAGHO	42.4	49.8	47.6	74.8	36.0
KVISK	59	55.5	45.9	95.0	71.2

3. RESULTS

Both MM5 and WRF simulations capture strong winds over the Vatnajökull ice cap (Fig. 3) as well as over the lowlands. In all simulations the flow is decelerated upstream of Mnt. Öræfajökull. The simulated near surface wind speed has a maximum immediately downstream of the highest mountain (Mnt. Öræfajökull). This maximum does not extend far downstream. There is also a secondary maximum of wind speed emanating from the edge of the same mountain. This secondary maximum extends far downstream. Accumulated precipitation measured at Skaftafell (SKAFT), Fagurhólsmýri (FAGHO) and Kvísker (KVISK) is compared with simulated precipitation in Table 1. Both models correctly simulate the dry area downstream of Mnt. Öræfajökull but tend to overestimate the precipitation on the windward side with the exception of WRF/2eq (named WRF Bao in Fig. 4). This overestimation can, to some extent, be explained by undercatchment of the rain gauges due to strong winds. The precipitation gradient in the WRF simulations (i.e., more precipitation at KVISK than at FAGHO) is in better agreement with observed gradient than is the MM5

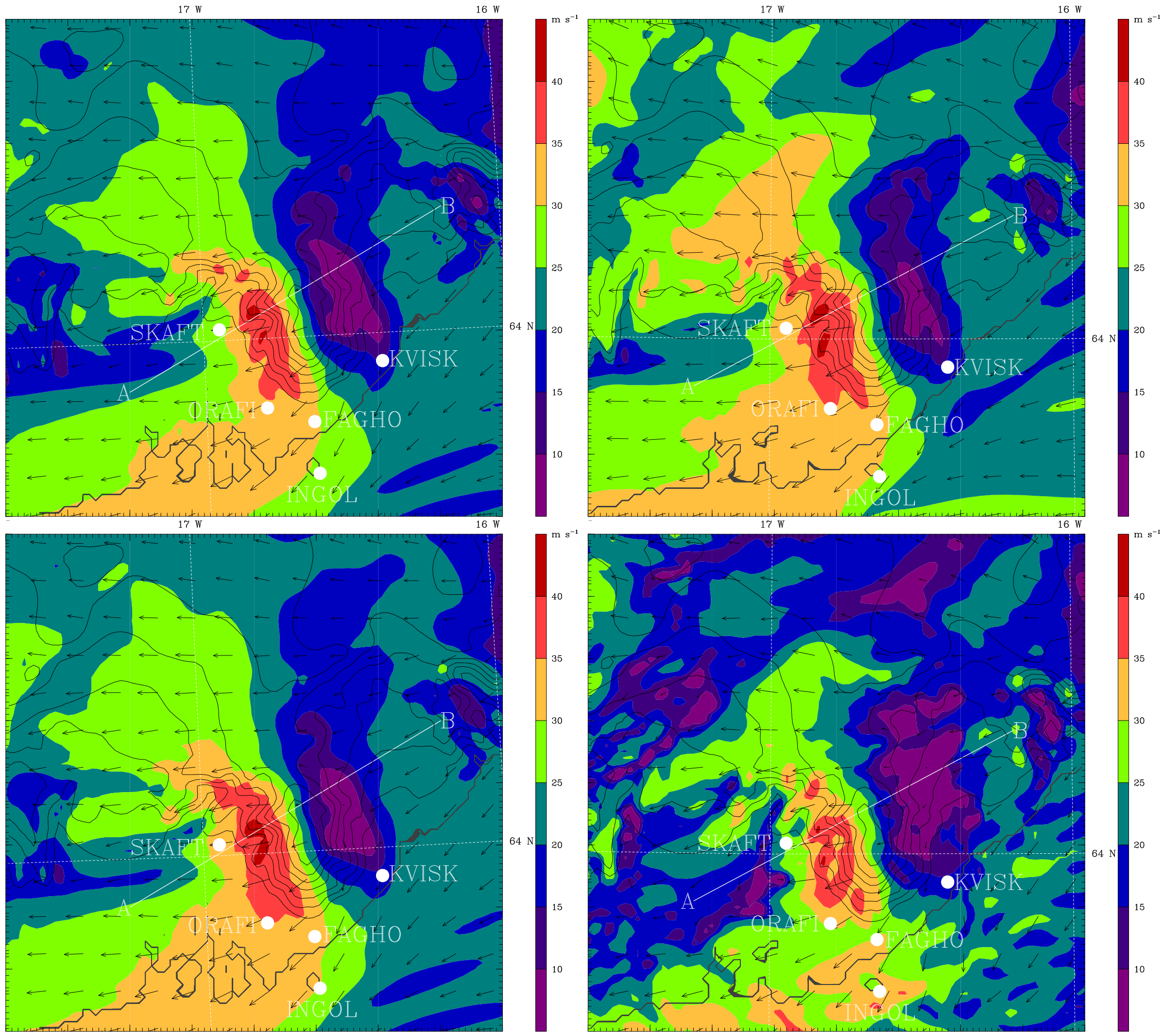

Figure 3: Simulated near surface wind speed [m/s] by MM5 (left panels) and WRF (right panels) at 16 September 2004, 06 UTC. Top panels show results from the ETA and MYJ boundary layer schemes and the bottom panel shows results using the new two equation PBL model.

simulation, although the precipitation amount in the MM5 simulation is closer to the observed values. In the WRF/2eq simulation the upstream blocking extends closer to location FAGHO than it does in the WRF/MYJ simulation. As heavy precipitation is often associated with strong winds this could to some extent explain the difference in simulated precipitation between the two WRF simulations upstream and at the tip of the mountain (stations KVISK and FAGHO). With regard to wind speed, there exists a noticeable quantitative difference between the four simulations. Figure 4 shows observed and simulated surface wind speed and temperature at Skaftafell (SKAFT). The WRF simulated downslope winds, using the MYJ PBL scheme, are in good agreement with the strength of the observed downslope windstorm, with the maximum wind speed as great as 29 ms^{-1}, whilst using the new two equation scheme surface winds only reach about 22 ms^{-1}. On the contrary, the MM5 simulated surface winds, with the new two equation model, are in better agreement to observations than when using the ETA scheme. Surface winds reach 22 ms^{-1} when using the two equation model whilst the winds in the MM5/ETA simulation only reach about 17 ms^{-1}. Further, the 2–meter temperature is captured considerably better by the WRF model than by MM5. On average, the MM5 simulated 2–meter temperature is 2–3 °C colder than measured while the 2–meter temperature in WRF is very close to the observed surface temperature. However, at other stations (ORAFI, KVISK, FAGHO and INGOL) away from the wind maximum, the difference in temperature and wind direction between the four simulations are small (not shown). At

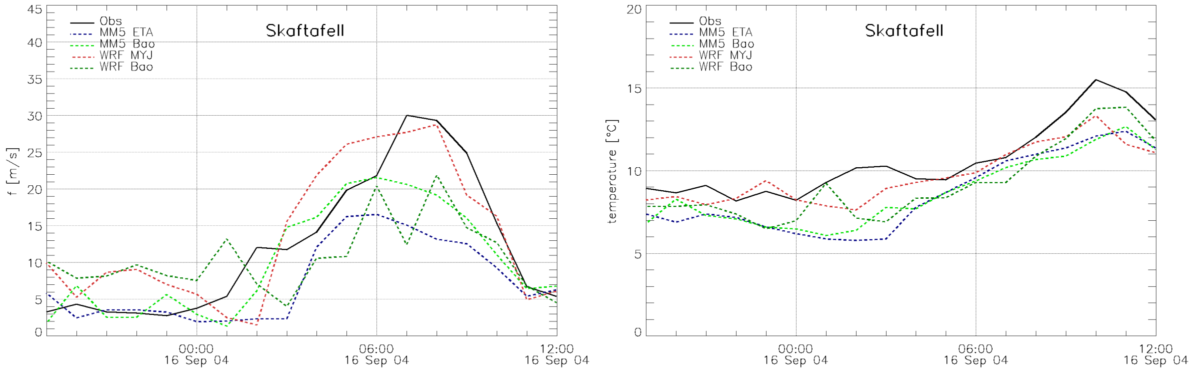

Figure 4: Observed (solid black) and simulated (blue dash – MM5/ETA, light green dash – MM5/2eq, red dash – WRF/MYJ, dark green dash – WRF/2eq) 10 meter wind speed [m/s] (left) and 2–meter temperature [°C] (right) at station Skaftafell (WMO# 4172 – SKAFT) in the lee of Mnt. Öræfajökull.

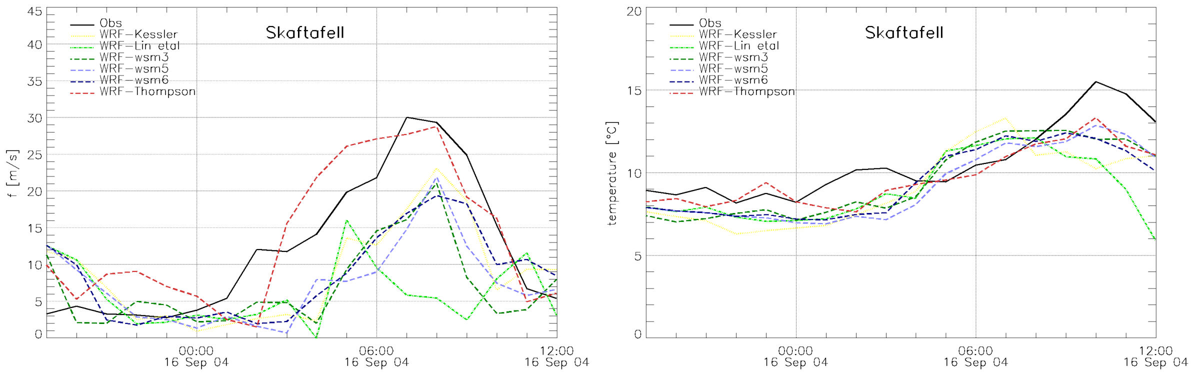

Figure 5: Observed (solid black) and simulated (dashed) 10 meter wind speed [m/s](left) and 2–meter temperature [°C] (right) at station Skaftafell (WMO# 4172 – SKAFT) in the lee of Mnt. Öræfajökull. Various colors represent various microphysic parameterizations within the AR–WRF model: Yellow – Kessler, light green – Lin et al., dark green – WSM3, ligth blue – WSM5, dark blue – WSM6 and red – Thompson scheme.

station Öræfi (ORAFI) the WRF/MYJ model overestimates the mean wind by approximately 5 ms^{-1} while MM5/ETA captures the wind field correctly. Both two equation simulations (MM5/2eq and WRF/2eq) show similar results, the wind speed being 2–3 ms^{-1} greater than observed values. At Kvísker (KVISK) both models perform similarly, the MM5 underestimates the winds slightly while WRF slightly overestimates them. At station Fagurhólsmýri (FAGHO) the MM5 simulations are very similar, both simulations consistently underestimate the corner wind and faile to capture the maximum wind strength by 7–8 ms^{-1}. The WRF models fare considerably better, but still underestimates the observed maximum winds (30 ms^{-1}) by 4 ms^{-1}. With the current model configuration, station Ingólfshöfði (INGOL) is off–shore in both models. Hence, observed and simulated fields can not be compared in a logical manner.

The intensity of the simulated downslope windstorm is not only sensitive to the PBL schemes but also to the cloud microphysics schemes. Figure 5 shows the variation of the AR–WRF simulated surface wind speed (left) and temperature (right) at Skaftafell that is caused by using various options of the cloud microphysics schemes. It is seen that there is a significant variation in the simulated maximum surface wind speed corresponding the different cloud microphysics schemes, and the Thompson scheme appears to produce the result in the best agreement with the observation. The surface temperature is also best simulated with the Thompsons scheme, being very close to observed temperature during the peak of the storm (04UTC to 08UTC on 16 September). During this period the AR–WRF model, using other microphysic parameterizations, overestimates the surface temperature at Skaftafell by 1–3 °C. However, the model does not capture the observed temperature maximum (15.5 °C) at 10UTC, but the Thompson scheme produces results that are closest to the observed values.

The sensitivity to cloud microphysics scheme can be explained by the fact that various schemes produce different upslope distributions of precipitation and hy-

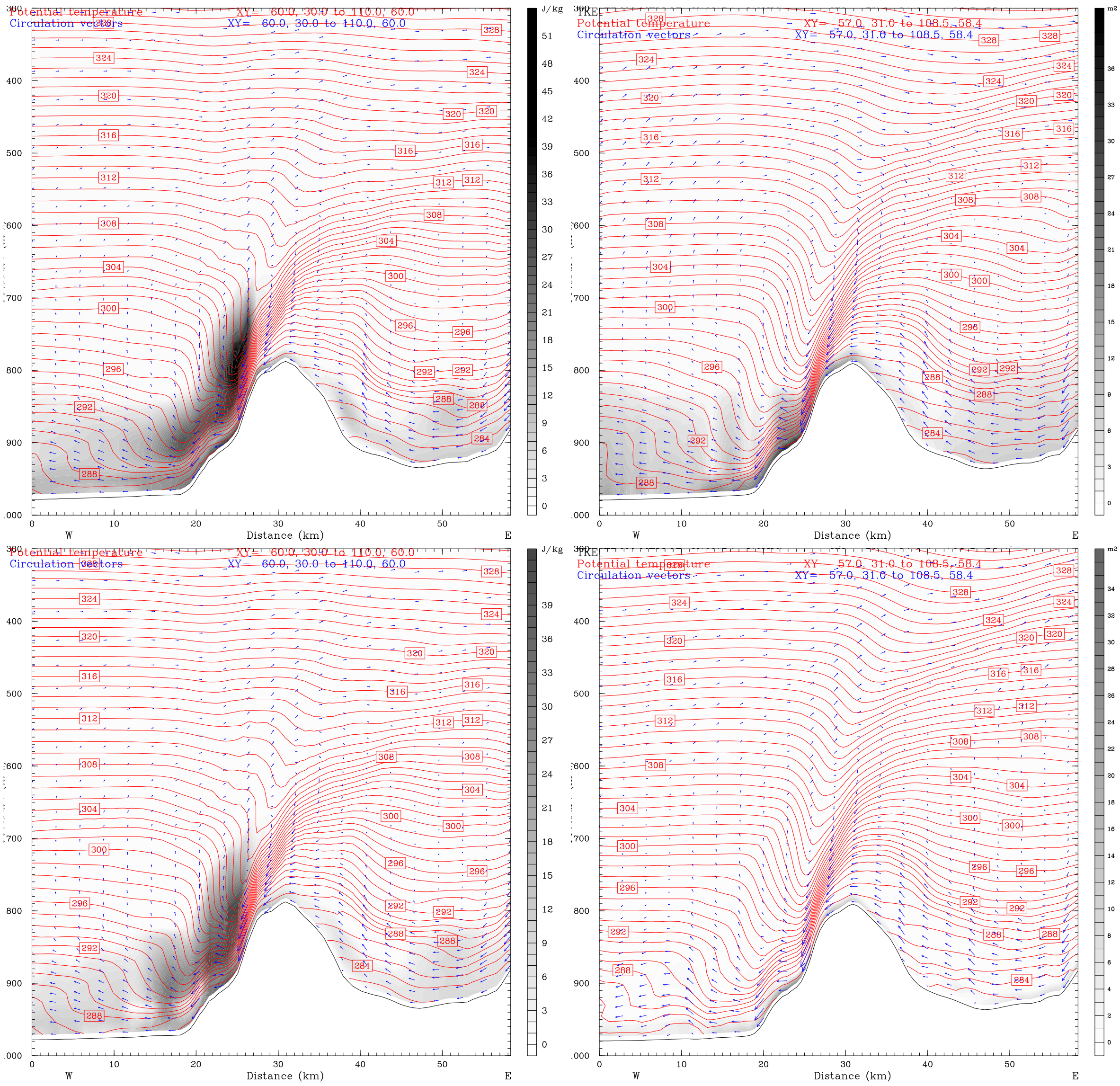

Figure 6: Cross section along line AB (cf. Fig. 3) showing potential temperature (red lines) [K], wind along the cross section (blue arrows) [m/s] and turbulent kinetic energy (TKE) [J/kg] for MM5 (left panels) and WRF (right panels) at 16 September 2004, 06 UTC. Top panels show results from the ETA and MYJ boundary layer schemes and the bottom panel shows results using the new two equation PBL model.

drometeors, resulting in variation in the upslope static stability. Since the intensity of downslope wind is directly related to the intensity of the downslope gravity-wave breaking that is strongly dependent on the upslope static stability, this sensitivity is the manifestation of the great impact of the upslope precipitation on the downslope wind speed.

Figure 6 shows a cross section along line AB in Fig. 3 from the four simulations. In both the MM5 simulations, the distribution of turbulence kinetic energy (TKE) shows that there is very strong mountain wave breaking between approximately 800 and 650 hPa and very little wave activity above 500 hPa. There is intense turbulence below 700 hPa associated with the wave breaking. At the surface, there is also a layer of high TKE. In spite of common features the MM5/ETA and MM5/2eq simulations reveal important differences in the wave and TKE structure. Between 18UTC and 00UTC on 15 September, there is stronger TKE between 900 and 700 hPa in the MM5/ETA simulation downslope of the mountain. The wavestructure is however very similiar. Few hours later, between 01UTC and 03UTC on 16 September, the wave penetrates considerably deeper in the ETA/2eq simulation. Surface wind speed at Skaftafell increase sharply from 3 ms^{-1} to 15 ms^{-1} whilst staying calm in the MM5/ETA simulation. The TKE is confined below the T_{pot}=286 K isoline in the MM5/2eq simulation but below the T_{pot}=289 K isoline in the MM5/ETA simulation. During the peak of the windstorm, between 06UTC and 09UTC on 16 September, there is stronger TKE aloft in the lee of the mountain in the MM5/2eq simulation but the wavestructure is now very similar. After 09UTC there is very little difference between the two MM5 simulations.

The wave breaking, simulated by the WRF model, on other hand, differs from the wave breaking simulated by MM5. Particularly, the WRF simulated wave breaking is much weaker than that in the MM5 simulation. Interestingly, there is high TKE production at the surface in the WRF simulation as in the MM5 simulation. The cross–sections reveal greater differences between the two WRF simulations (WRF/MYJ and WRF/2eq) than there appear to be between the two MM5 simulations. Firstly, there is very little TKE aloft (900–700 hPa) in the WRF/2eq simulation between 21UTC and 03UTC on 15–16 September. Both simulations show similar characteristics between 03UTC and 06UTC on 16 September but after that, between 07UTC and 10UTC there is considerably greater TKE aloft in the lee of the mountain in the WRF/2eq simulation.

4. DISCUSSION AND CONCLUSIONS

The major difference between the MM5 and WRF simulations is in the wave breaking. In the MM5 simulations, there is greater dissipation in the downslope wind associated with greater TKE production below 600 hPa at all times than there is in WRF/MYJ. In the WRF/MYJ simulation, the dissipation mainly takes place between 950 and 700 hPa. After 03 UTC, 16 September, it is confined between surface and 800 hPa. The difference in the intensity of the simulated downslope winds can be explained by less dissipation associated with turbulence in the WRF/MYJ simulation than in the WRF/2eq and the MM5 simulations. Since upper air observations are not available to verify the simulated wave breaking, the accuracy of the simulated surface winds and temperature is the only measurable performance of both the MM5 and WRF models for this windstorm event.

Another major difference between the MM5 and WRF models is the different characteristics revealed when using the two equation PBL model. In WRF surface wind speed, in the lee of the mountain, is greatly reduced compared to the MYJ boundary layer scheme. This is in the opposite compared to the MM5 simulation, there the two equation model gives rise to greater surface winds that are closer to observed values.

Given the lack of upper air observations for this downslope windstorm event and the limitation of a single–case study, the results from this study are far from being conclusive. Further studies are needed to address the question as to whether or not the advanced numerics in the WRF model makes it better suitable than the MM5 model for high resolution simulations/forecasts of downslope windstorms in Iceland.

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